THE PHYSICAL, CHEMICAL, AND BIOLOGICAL NATURE OF PIGEON LAKE, A LAKE MICHIGAN COASTAL LAKE

by

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INTRODUCTION

Pigeon Lake (T6N, R16W, Section 16, Ottawa County), because of its location, is one of Michigan's unique lakes. It represents the terminus of Pigeon River, before the river enters Lake Michigan, and because of its confluence with this great lake, Pigeon Lake is one of the few estuarine water bodies along the coast. Lying behind large sand dunes, with Lake Michigan visible through its outlet, Pigeon Lake retains a special esthetic appeal. Fishermen (both summer and winter), water skiers, and sailors use Pigeon Lake for recreation and access to Lake Michigan. Boaters and fishermen on Lake Michigan frequently use Pigeon Lake for a safe harbor, because of a deep channel which extends from Lake Michigan along the south side of Pigeon Lake. In addition to these uses, Pigeon Lake is also the water body from which the J.H. Campbell Power Plant draws cooling water. Because of these three influences (confluence with Lake Michigan, Pigeon River emptying into it, and cooling water drawn from it), Pigeon Lake is a complex, interrelated ecosystem subject to considerable change. Presence of the river, Lake Michigan, and cool, well oxygenated Lake Michigan cooling water coupled with its natural beauty and diverse fish populations have made Pigeon Lake popular with people. Many cottages ring its shores and a Michigan Department of Natural Resources (MDNR) public access site allows the public to use this area freely. This report documents the present physical, chemical, and biological conditions in Pigeon Lake and compares them with conditions in other lakes in the immediate vicinity. The report also summarizes all available data we have collected on Pigeon Lake and complements our other studies of the Campbell Plant area.

In Pigeon Lake, fish populations vary according to the dominant habitat. East of Lakeshore Drive is the entrance of the Pigeon River. Logs, sticks, strong current, and thick vegetation have created excellent habitat for riverine species like smallmouth bass, madtoms, carp, and black crappies with yellow perch and bowfin abundant in the shallower, littoral areas. The limnology of this area is strongly influenced by the river, which carries seasonally high loads of nutrients, chlorides, and sediments. Because of these high nutrients, productivity is high and water clarity is low; little or no thermal stratification occurs in summer because of the currents.

West of Lakeshore Drive the lake looses much of its riverine character. This section most resembles a typical inland lake. It is very productive because of its shallowness and abundant nutrient supply from the Pigeon River, as evidenced by abundant macrophyte growth. Typical fish species are largemouth bass, sunfish, northern pike, perch, and crappies.

The western-most section, confluent with Lake Michigan, is strongly influenced by the J.H. Campbell Plant. Water is drawn from Lake Michigan through this section of Pigeon Lake and discharged to Lake Michigan after passing through the plant. This section is deep, sandy, sparsely vegetated, and does not stratify in summer. Fish species typical of both Pigeon Lake and Lake Michigan frequent the area. Adult alewives, salmon, trout, burbot, and larvae of whitefish and fourhorn sculpin were all collected at one time or another in Pigeon Lake, testifying to its uniqueness as a spawning ground and area of forage fish abundance for Lake Michigan fish.

Studies on Pigeon Lake have been limited to MDNR field research, historical information on land use and settlement in the area, and a Michigan

State University report (Consumers Power Company 1975) covering the biological nature of the lake. We have compiled the information for this report from all available literature including our present (Jude et al. 1980) and past studies on the benthos, fish larvae and juvenile and adult fish in Pigeon Lake (Jude et al. 1978, 1979a; Winnell and Jude 1979, 1980). To complement previous studies, a survey was sent to many fishermen and residents of Pigeon Lake in the winter of 1979-1980. To fill information voids regarding bathymetry, water chemistry, fish spawning sites, zooplankton populations, and macrophyte composition, special field studies were performed in 1980.

Presented in this publication is a series of sections covering the physical, chemical, and biological nature of Pigeon Lake. A detailed map was constructed, since none was available previously, and information was gathered from area sportsman on their attitudes about recreation in the Pigeon Lake area. Limnological data were gathered and compared with data on area lakes. Algae, aquatic macrophytes, zooplankton, and benthos were surveyed to provide baseline information. Our strongest data sets were on adult, juvenile, and larval fish. Extensive discussions of important species are presented along with data on their use of Pigeon Lake as a spawning or nursery area. Because of the considerable influence of man on Pigeon Lake, particularily concern over the potential effect of the J. H. Campbell Plant, we wanted to gather all available information on the past and present biological and limnological condition of the lake. From these data, we hope to characterize the lake before and after many of the modern influences shaped its present trophic status and make an assessment of the stability and productivity of the biological organisms, expecially fish. These findings will then be related to addressing the main driving forces responsible for maintaining the lake in its present physical, chemical, and biological form.

STUDY AREA

Pigeon Lake is located in Port Sheldon Township (T6N, R16W, Section 16) Ottawa County, Michigan. Pigeon Lake is the natural collecting basin for the Pigeon River before it enters Lake Michigan. The Pigeon River drainage area (approximately 155 km^2) supplies a flow of 1.12-1.26 m^3/s to Pigeon Lake (Water Resources Commission 1968). The J.H. Campbell Power Plant is operated by Consumers Power Company. Units 1 and 2 use 18.7 m^3/s for cooling condensers, causing the natural flow of Pigeon Lake into Lake Michigan to be directed through the plant. Thus Lake Michigan water supplements Pigeon Lake water which is then drawn into the plant and discharged (after being heated 9-10 C) to a canal approximately 1 km north of the entrance of Lake Michigan to Pigeon Lake. Two stone jetties (366 m long) at the entrance of Lake Michigan to Pigeon Lake ensure adequate flow of intake water to the plant. During winter months, the entrance channel is kept from icing by recirculation of heated discharge water which is piped along the north jetty and released into the intake canal.

The shoreline of Pigeon Lake reflects the general use of the lake as a recreational resource. A public access boat ramp maintained by the Michigan Department of Natural Resources (MDNR) and privately owned ramps and docks are used extensively during spring, summer, and fall. The deepest part of the lake, located in the western portion, is 8.25 m; a moderately deep channel (2.1-3.5 m) follows the southern shoreline, which accomodates many docking facilities; approximately 40 exist in the whole lake. The eastern third of the

lake has a maximum depth of 3.25 m, an organic bottom, and extensive beds of aquatic macrophytes. The western two-thirds has a bottom of mixed organic material and sand, while the extreme west end has a sand bottom. Before the power plant was built, the channel connecting Pigeon Lake with Lake Michigan was approximately 70 m long with a width varying from 30 to 40 m where it enters Lake Michigan. With onset of power plant operation in 1963, this channel was widened to the present width of 40 m for its entire length.

We established sampling stations in all major habitat types. Two stations in the far eastern section of Pigeon Lake were chosen because of their proximity to the entrance of the Pigeon River. Station Y (Fig. 1) was an open water station approximately 1.8 m deep. Aquatic vegetation was extremely dense in summer and autumn and the bottom was soft peat (Consumers Power Company 1975). Beach station T (Fig. 1) was of similar bottom and vegetation type. Depth at this station ranged from 0.3 to 1 m with large obstructions (logs, branches, etc.) common.

Beach station V and openwater station X were in the "undisturbed" part of Pigeon Lake. Vegetation density was notably less at these two stations when compared with stations Y and T, which had a similar bottom type. Openwater station X ranged in depth from 1.2 to 2.1 m. Two stations (M and S) were influenced by inflowing Lake Michigan water. Open water station M (Fig. 1) was approximately 7 m deep and lacked the dense vegetation occurring at other open water stations. Beach station S (Fig. 1) had a fine sand bottom and steep slope, which restricted the amount of the shoreline that could be seined. In 1978 and 1979 the sampling scheme in Pigeon Lake was modified from 1977, by deleting stations T and Y to accomodate other program requirements. Sampling during 1978 was continued in the "undisturbed" part of Pigeon Lake which included beach station V and open water station X. Due to dredging activities during construction of Unit 3, beach station S had to be relocated 100 m farther along the Pigeon Lake shoreline toward Lake Michigan (Fig. 1). In 1979, due to the dredge company's boat traffic, gillnetting was discontinued after April at station M.

HISTORY

The history of Port Sheldon is recorded in a document titled Whispering Sands, A History of Port Sheldon (Kemperman et al. 1966). All of the following material is summarized from that publication. In 1835 the Port Sheldon Land Company was formed with the purpose of building a city which would become the great metropolis of the west as Chicago is today. Grand Haven, at the mouth of the Grand River, was first selected as the site for Port Sheldon. Attempts to purchase the needed land were unsuccessful. The Black Lake estuary, where Holland stands today, and Pigeon Lake, a small indentation in the shoreline of Lake Michigan halfway between Holland and Grand Haven, were the next two choices for Port Sheldon. Although Black Lake offered the better harbor site, Pigeon Lake was selected.

The company bought 600 acres of land from the Federal Government at $1.50 per acre. The ground was covered with hemlock and pine trees. There were also thousands of passenger pigeons present that were caught and sold in the east. Pigeon Lake probably received its name from the presence of so many pigeons as this area of Michigan was a favorite nesting ground for them. They were so abundant that in 1856 passenger pigeons covered 500 to 600 acres of land north

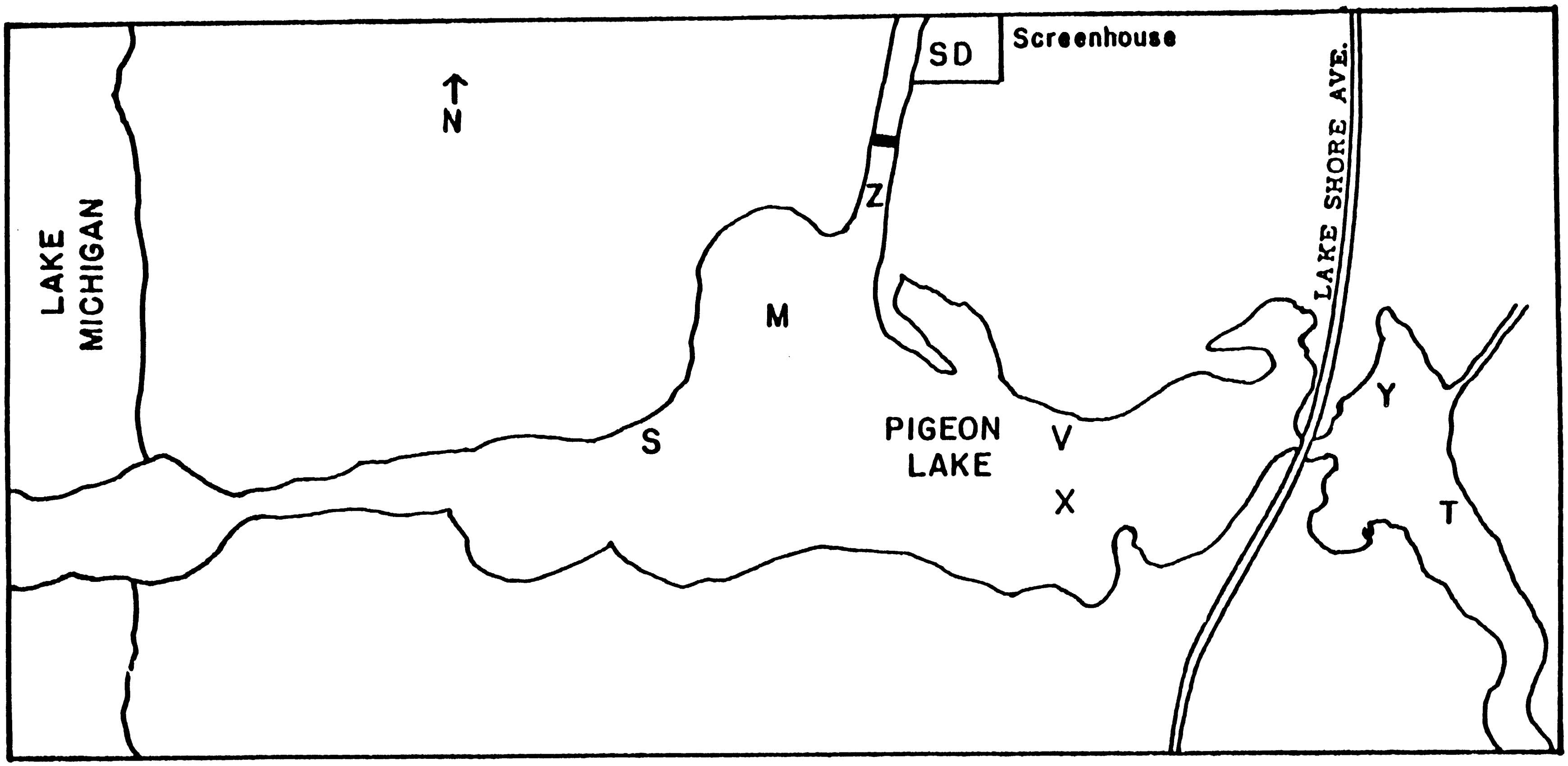

Fig. 1. Scheme of the J. H. Campbell Plant showing Lake Michigan and seven sampling stations in Pigeon Lake (S, T, V, M, X, Y and Z) and the entrainment location (SD) in the discharge canal of the Campbell Plant.

of Pigeon Creek in Ottawa county. The Port Sheldon Company never developed a harbor in Pigeon Lake. Although a lighthouse was built, the entrance to Pigeon Lake remained unpassable for almost any boat. Most large ships would anchor outside Pigeon Lake and send small boats into the lake. By 1840 the Port Sheldon Company had gone bankrupt due to poor money management and lack of industry and foresight from people who planned the town and who tried to build it. By 1890 most of the virgin lumber had been cut. A soil erosion problem developed, but not until 1916 did people become alarmed. Then the first plantings of seedlings and cuttings took place. Between 1916 and 1919, 35,000 trees were planted. By 1932 dune grass and pine trees were being planted to control erosion. In 1939 a Conservation District Nursery was established to grow stock for reforestation. It produced pine and spruce seedlings for many years and is still in operation at the present time. By the early 1930s strawberry, raspberry, and blueberry growers had moved to Port Sheldon. A Christmas tree and nursery industry was developed as a byproduct of the soil conservation program. At present, the nursery seedling business is very specialized and plants are shipped all over the United States.

There was a shipyard at the mouth of Pigeon River and the last ship worked on was the Nancy Dell. It was never completed, and part of the lumber was eventually used to build a cottage. Consumers Power Company purchased a large section of land on the north side of Pigeon Lake and on 2 October 1963, Unit 1 of the J. H. Campbell fossil fuel power plant began operation, followed by Unit 2 in spring, 1967. Unit 3 began operation in fall, 1980. With the increased flow of Lake Michigan water into Pigeon Lake, as a result of power plant operation, there was a change in ichthyofauna in Pigeon Lake confirmed by long-time residents and anglers in the area. Prior studies conducted by MDNR have established the presence of brown trout in the Pigeon River during 1969 and in 1964 the river was treated to control sea lampreys.

METHODS

MAPPING TECHNIQUES

In the course of gathering information for assessing the physical and chemical nature of Pigeon Lake it became apparent that an accurate and current hydrographic map was unavailable. Therefore, to better understand the lake basin morphology and provide some insight into factors affecting the water chemistry of Pigeon Lake, a hydrographic map was constructed.

Bathymetric sampling transects oriented in a north-south direction were established using shoreline irregularities or distinct onshore features such as trees, houses, or bridges as reference points. Sampling locations were identified by the intersection of the sampling transect and one of a series of perpendicular, east-west transects. In this way soundings taken in the field were accurately transcribed onto a lake map traced from an aerial photograph from which reference points were easily located. Depth measurements were taken using a thermistor cord calibrated in 0.25-m intervals and equipped with a 11-kg weight. Bathymetric measurements for that portion of Pigeon Lake lying west of Lake Shore Dr., consisting of the central and west basins, were taken 5 May 1980, while measurements for the portion east of Lake Shore Dr., referred to as the east basin, were taken 2 June 1980. A hydrographic map was constructed from bathymetric measurements in accordance with procedures outlined by Welch (1948).

WATER CHEMISTRY

Station Locations

Sampling stations were selected to assess the chemical nature of the central basin of Pigeon Lake - influenced by the Pigeon River, the west basin - influenced by Lake Michigan, and the intake canal - influenced by both Lake Michigan and the Pigeon River (Fig. 2). The central basin sampling station was located in the eastern portion of the lake directly north of the island at a depth of 2.5 m. The west basin station lies in the narrow western half of that basin midway between the north and south shores in 8 m of water. The intake canal station (4.5 m) was within the transition zone between the west and central basins. Sampling stations used in a 1975 study of Pigeon Lake conducted by Michigan State (Consumers Power Company 1975) were located in areas of the lake comparable to the stations just described (Fig. 2).

Water Temperature

Water temperatures were measured using a Hydrolab model 74 thermistor. Measurements were taken at surface, mid-depth, and bottom except at the central basin station where mid-depth sampling was deleted.

pH

The acid/alkaline nature of the lake (pH) was measured colorimetrically using a LaMotte wide range pH test kit.

Phosphorus, Nitrogen, Chloride

Anaylses of phosphorus and nitrogen compounds and chloride were according to Environmental Protection Agency guidelines (Environmental Protection Agency 1974). These parameters were measured using a Technicon Autoanalyzer II system. Specifically, methods employed for the analysis of these parameters were as follows: total phosphorus and orthophosphate - automated colorimetric ascorbic acid reduction method; total Kjeldahl nitrogen - modified automated phenate method; nitrate - automated cadmium reduction method; ammonia - automated colorimetric phenate method; chloride - automated mercuric thiocyanate method.

Secchi Disc

A Secchi disc was used to measure light penetration in surface waters. These readings can be an indication of the productivity of lakes. Many factors, both biological (algae and soluble organic acids for example) and non-biological (suspended inorganic particulate matter such as clay), contribute to the turbidity of surface waters. Methods described by Welch (1948) were employed for this analysis.

Dissolved Oxygen

Dissolved oxygen is essential for the survival of all life stages of fish and most other aquatic organisms. Oxygen taken up by heteretrophs is used to convert food and fuel reserves into more utilizable forms of energy. The decomposing activity of bacteria found in lake sediments is a major sink for

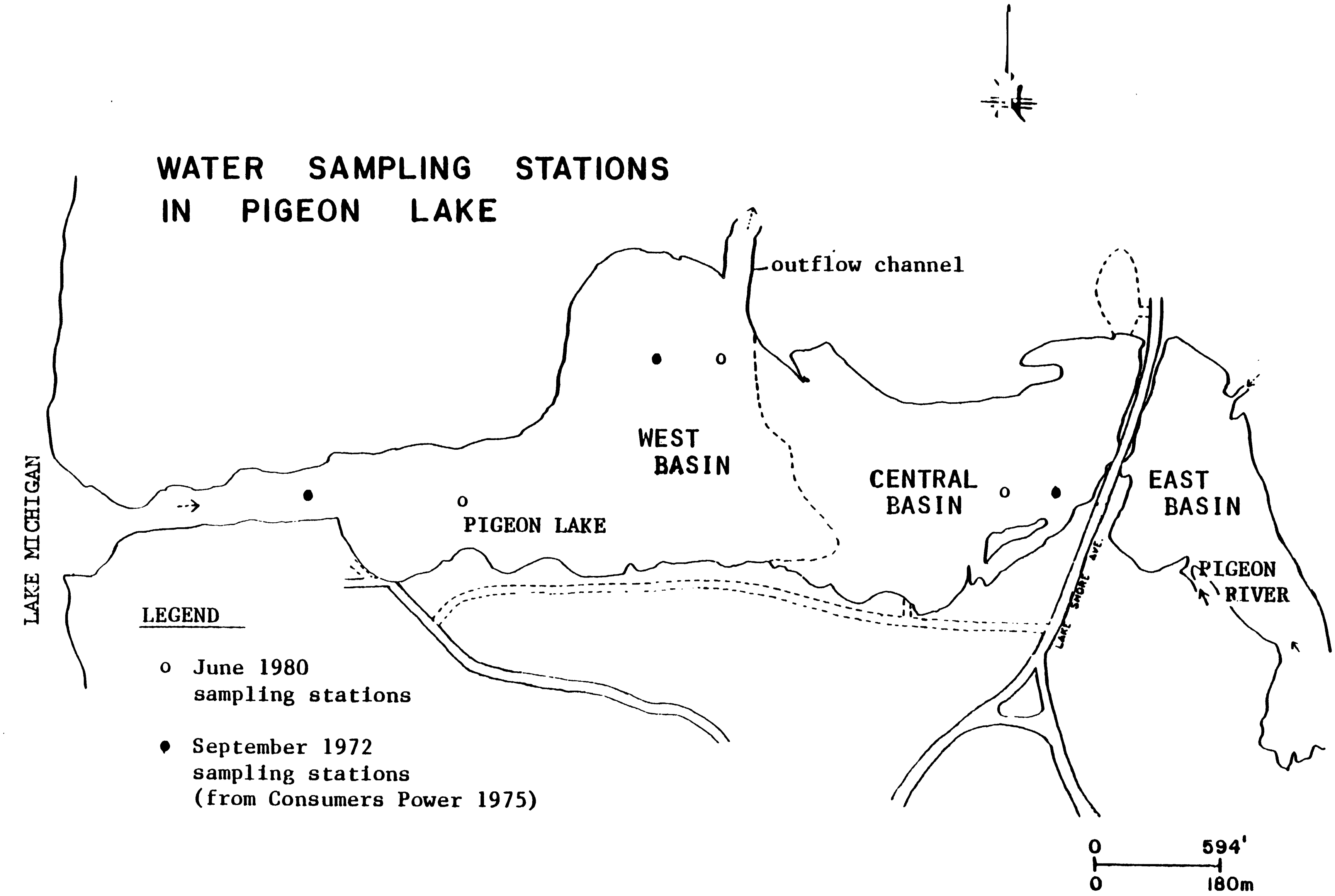

Fig. 2. Scheme of Pigeon Lake showing the location of 1980 and 1972 water sampling stations.

dissolved oxygen and is responsible for the anoxic (no dissolved oxygen) conditions observed in the hypolimnetic waters of many eutrophic lakes. Wave action and the photosynthetic activity of aquatic plants and algae are the primary means by which lake waters are oxygenated.

Water samples for the analysis of all chemical parameters including dissolved oxygen were collected with a Kemmerer water sampler. Dissolved oxygen was determined according to Standard Methods (American Public Health Association 1971) using the azide modification of the iodometric (Winkler) method and PAO (phenylarsene oxide) as the titrant.

Hardness, Total Alkalinity

Hardness was measured according to Standard Methods (American Public Health Association 1971) using the EDTA method. Results for both hardness and alkalinity were reported as mg/L as calcium and magnesium. Total alkalinity was also measured using techniques recommended by Standard Methods. The indicator was bromo-cresol green and 0.025 N sulfuric acid was the titrant.

ALGAE

Samples of algae were wet-mounted on a slide and examined under high power for presence of algal species. Keys used included Patrick and Reimer (1966 1975), Hustedt (1930), and Prescott (1951).

AQUATIC MACROPHYTES

A visual assessment of the aquatic plant communities was conducted June-August 1980. Plants were identified in the field when possible, otherwise they were returned to the laboratory for further efforts at identification. The key used was Fassett (1972). Distributions of major species were recorded for each area of Pigeon Lake. A map of Pigeon Lake was then prepared depicting major abundances of the species observed.

ZOOPLANKTON

Sampling for zooplankton was conducted on 18-19 June 1980. Two areas of the lake were sampled; beach station S (Fig. 1), influenced by Lake Michigan water which is drawn in by the plant, and an area near the Lakeshore Drive bridge, similar to the station A used by Tack and others (Consumers Power Company 1975).

During both day and night, 5-min midwater horizontal tows were conducted at each station. Zooplankton were collected using a 0.5-m diameter, nylon plankton net of number 10 mesh (153-micron aperture). Samples were preserved with buffered 10% formaldehyde. Zooplankton were identified and percent composition of species in each sample was generated.

BENTHOS

Benthos samples were collected on 2 June 1977 along six transects in Pigeon Lake (Fig. 3). There were four transects (PL1, PL2, PL3, and PL4) in the western basin of Pigeon Lake; all had two stations located along each

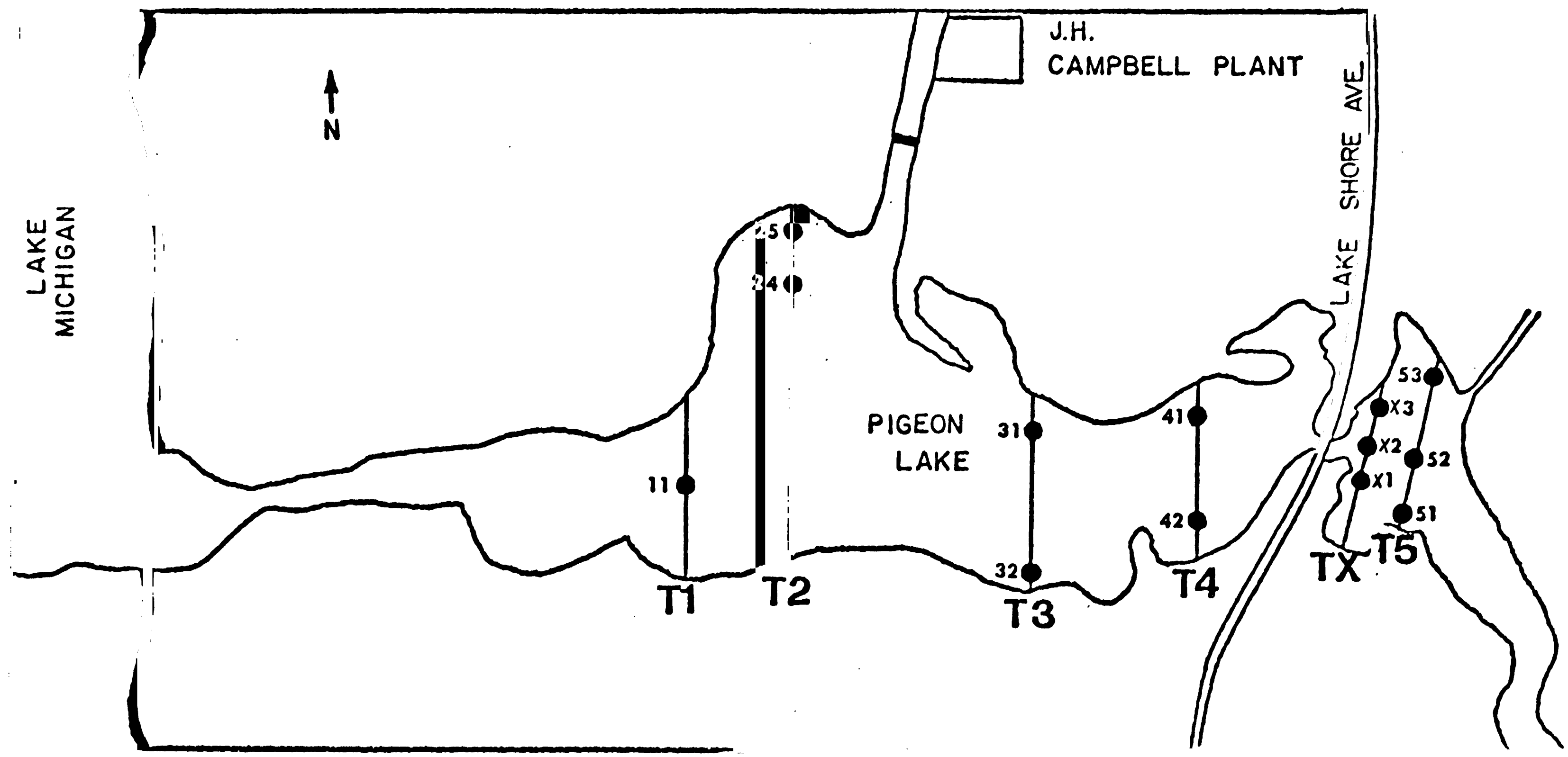

Fig. 3. Transect and station location for benthic macroinvertebrate sample collection in Pigeon Lake near the J. H. Campbell Plant, June 1977 (T = transect).

transect except PL1 which had only one station. The remaining two transects were in the eastern basin (PL5 and PLX). Each station was sampled three times (replicates A-C) resulting in 39 samples.

Sample sites along a given transect in Pigeon Lake were selected with respect to presence of aquatic macrophytes, visually observed sediment type, and lake bottom slope and depth. Site selection was subjective with respect to the characters mentioned above. Description of benthos at a specific station, transect, basin, and the lake as a whole was dependent upon habitat selected. Therefore, while a given sample unit of the lake (station, transect, basin, or lake) may be used to describe the area in the vicinity of that unit, it is dependent upon habitat selected.

Benthos samples were collected with a Wildco Ponar grab sampler, modified so that the side plates extended up to the central axis that rotates the jaws for cocking and closing. Extension of the side plates prevented loss of material. Upon collection, samples were washed through a 0.35-mm mesh net. The portion retained in the net was stored in 1-quart Mason jars and preserved in 4% buffered formaldehyde solution. Samples were returned to the Great Lakes Research Division Benthos Laboratory in Ann Arbor, Michigan for sorting and identification.

ADULT AND JUVENILE FISH

Seining

Adult and juvenile fish were sampled using a 0.6-cm (0.25-in) mesh nylon seine, 15.2 m x 1.8 m (50 ft x 6 ft) including a 1.8-m (6-ft) bag. The seine was hauled parallel to shore for a distance of 61 m (200 ft). Duplicate non-overlapping hauls were performed both day and night at all seining stations. Monthly seining was performed from June through November at three beach stations in Pigeon Lake during 1977 and two stations in 1978 and 1979. See Jude et al. (1978, 1979b, 1980) for details.

Pigeon Lake stations had very little current, and the direction of seining was northwest to southeast at station T, southwest to northeast at station V and north to south at station S (see Fig. 1).

Gillnetting

Nylon experimental gill nets 36.6 m x 1.8 m (120 ft x 6 ft) were set once a month for approximately 12 h during daylight and 12 h during the night. Each gill net was composed of 12 panels, with each 3.0-m (10-ft) panel starting at 1.3-cm (0.5-in) bar mesh and proceeding in 0.6-cm (0.25-in) increments up to 7.6-cm (3-in) mesh, with the last panel having 10.2-cm (4-in) mesh. Two of these nets fastened end to end were set together and considered replicates. All gill nets were set perpendicular to shore in Pigeon Lake at two stations, Y (1.5 m) and M (6 m) (see Fig. 1) during 1977 and at M in 1978; gillnetting was deleted in 1979.

Adult Fish Processing

Each replicate from seine and gill net catches was labeled and kept separate in plastic bags. Fish were processed fresh when time permitted, or frozen at the J.H. Campbell Plant. For laboratory examination, fish in each

bag were thawed, separated by species, then grouped into size classes. When large numbers of a particular size class for an unusually abundant species were present, a subsample was randomly selected from the group and the remaining fish weighed (herein referred to as the mass weight) and discarded. Gonad condition of adult fish was also described according to five stages of development (for details see Jude et al. 1978).

Population Estimates of Northern Pike and Largemouth Bass

To assess population abundance a mark and recapture study was conducted in 1977 and 1978. Species considered for the study included yellow perch, largemouth bass, smallmouth bass, northern pike, bluegill, and black crappie. Since Pigeon Lake is an open system, a major factor in selecting species to study was to consider the amount of potential interchange between Lake Michigan and Pigeon Lake. Since fairly large numbers of yellow perch live in Pigeon Lake, too many would have had to be marked for a valid estimate; therefore this species was not studied. Migration of fish from or into Pigeon Lake would violate a basic assumption used in population estimates (Ricker 1975). The primary species studied were northern pike, largemouth bass, and smallmouth bass. From baseline surveys on Pigeon Lake by our research group, it was determined that bluegill and black crappie numbers were too low to be adequately assessed. Grass pickerel were marked because they were inadvertently collected along with northern pike.

An electrofishing boat (Coffelt Electronics Company Inc. - Model VVP-15) was used to collect most fish in the study. The generator was designed to deliver 300 V pulsating DC current to minimize the number of deaths due to shocking. Stunned fish were brought aboard by dip net and held in a live well for recovery. Other capture gear were gill nets and seines. Gillnetted fish judged to be in good condition (i.e., able to swim away) were marked and released. Fish taken by seine and gill net were included in the electrofishing catch corresponding to the same time period. Northern pike greater than 299 mm total length and bass (largemouth and smallmouth) greater than 219 mm total length were tagged with spaghetti tags. Smaller northern pike, largemouth bass, and smallmouth bass along with all grass pickerel, were fin clipped using a different clip for each period. Spaghetti tags (Floy Tag & Manufacturing, 4616 Union Bay Place Northeast, Seattle, Washington 98105) were individually numbered and inscribed with either a Consumers Power or University of Michigan address. Tags were inserted in the epaxial muscle below the dorsal fin.

Fish were marked during four periods between 21 September 1977 and 3 November 1977, and during five periods between 6 September and 25 October 1978. These periods ranged from 2 to 3 days. Most shocking was done at night because of higher catch-per-unit-effort. Each trip lasted 4-9 h. Shallow areas (less than 1 m) of Pigeon Lake were thoroughly covered during the first two periods. From this experience it was learned where pike and bass were common in the lake. These areas were covered during electrofishing from then on and less effort was expended in areas containing lower densities of pike and bass. Areas which contained high densities of fish varied from one collection period to the next and were heavily fished when encountered. Because Pigeon Lake gradually narrows at its upstream end to become Pigeon River and the distinction is by no means exact, an arbitrary upper boundary was designated (Fig. 4). Fish may have moved in and out of the area designated as Pigeon Lake and into the Pigeon River, but this effect was assumed to be minimal.

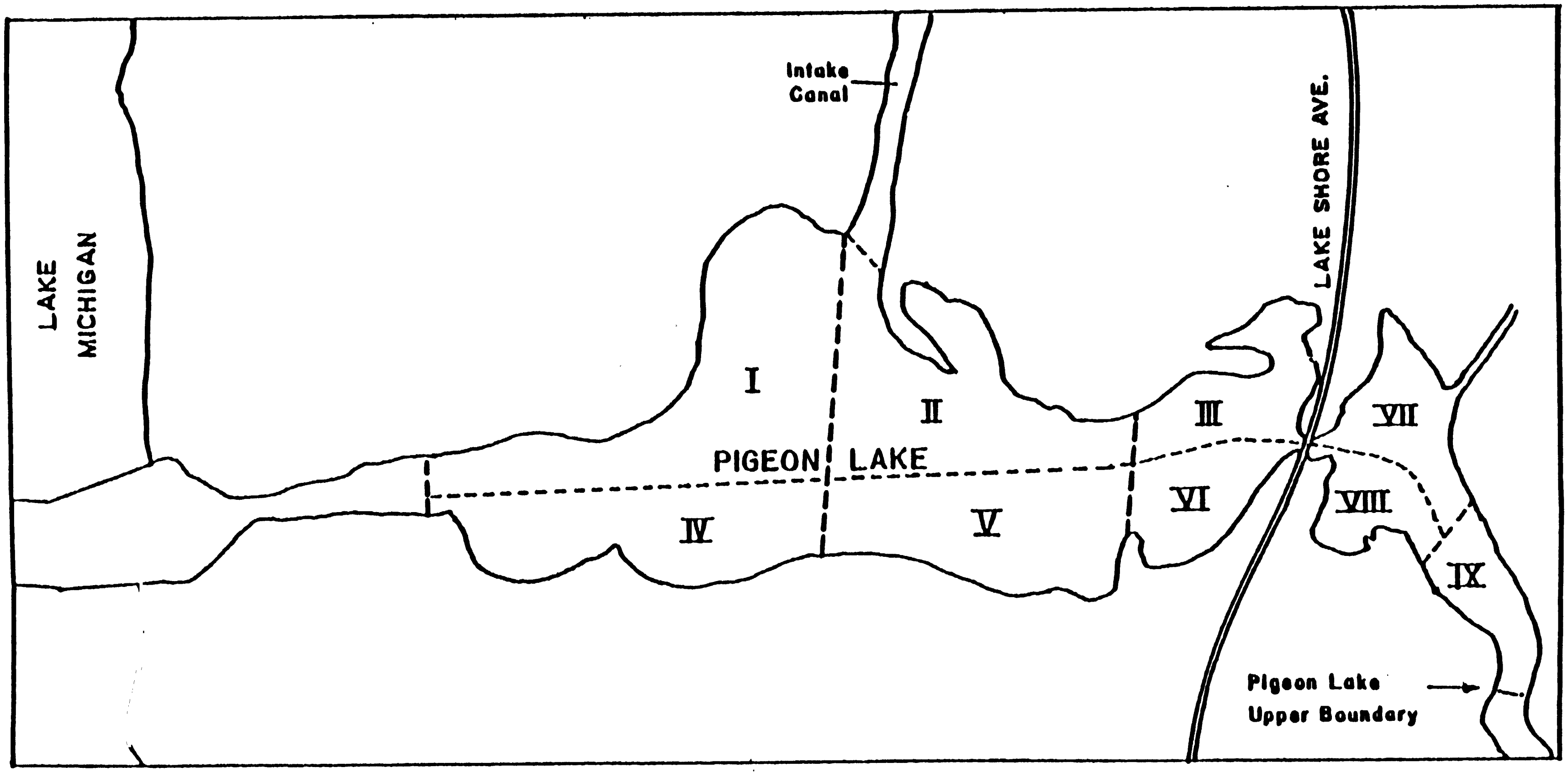

Fig. 4. Scheme of Pigeon Lake showing the location of nine electrofishing areas designated for the game fish population study conducted during fall 1978 at the J.H. Campbell Plant, Port Sheldon, Michigan.

Pigeon Lake was divided into nine areas (Fig. 4). Species, length, weight, and area of capture were noted for each tagged fish. Recaptured fish were examined for tag number and this information recorded with the area of capture. Observations made during the mark and recapture study period in Pigeon Lake indicated no fishing success among the few fishermen seen. Thus, it was assumed that during the study period fishing mortality was low enough to satisfy assumptions necessary to make a population estimate (Ricker 1975).

FISH LARVAE

Fish larvae, arbitrarily defined as any fish less than 2.54 cm total length, were collected using a 0.5-m diameter, nylon plankton net of no. 2 mesh (351-micron aperture). A Rigosha flowmeter (Rigosha and Co. Ltd., 10-4 Kajicho 1-Chome, Chiyoda-Ku, Tokyo, 101 Japan) attached to the center opening of the plankton net determined volume of water sampled.

Fish larvae were sampled both day and night. Duplicate 61-m (200 ft) surface tow samples were collected at beach stations S, T and V during 1977 and stations S and V during 1978-1979 (Fig. 1). Horizontal 5-min fish larvae tows were also performed at discrete depths at stations M (0.5-, 2.5- and 4.5-m tows), X (0.5-m tow), Y (0.5-m tow) and Z (0.5- and 2.5-m tows) (Fig. 1).

Fish larvae and eggs were removed from samples with the aid of a binocular microscope and a lighted sorting chamber (Dorr 1974a). Larvae were usually measured to the nearest 0.1 mm (total length), although in large samples larvae were sometimes measured to the nearest 0.5 mm. Larvae and egg data were entered on coding forms and later keypunched. Numbers of larvae and eggs captured were adjusted to number per 1000 m^{3} via a computer program.

In 1977 we tentatively designated all clupeids as alewife. Alewife and gizzard shad larvae are difficult to separate and since gizzard shad adults are common in the area, some of the larvae identified as alewives may have been gizzard shad. In 1978-1979 we developed the expertise to distinguish between the two species.

RESULTS AND DISCUSSION

RECREATIONAL AND COMMERCIAL USE

Introduction

From 1978 to fall 1980, construction workers and divers for Consumers Power Company used Pigeon Lake as a safe harbor for their vessels during their work on the new offshore intake and discharge structures for the J.H. Campbell Plant's Unit 3. In addition, water to cool Units 1 and 2 is drawn from Pigeon Lake through an intake canal and into the J.H. Campbell Plant and then discharged into Lake Michigan. Water drawn from Pigeon Lake is replaced mainly by water from Lake Michigan which enters Pigeon Lake through a channel constructed between the two lakes; a small quantity is replaced by flow of the Pigeon River into Pigeon Lake, particularly in the spring.

Pigeon Lake also serves as a recreational resource. A Pigeon Lake recreation survey was conducted during 1980 with the following objectives: 1) to determine the more popular forms of recreation for Pigeon Lake; 2) to determine the extent and kinds of angling on the lake; 3) to determine the

effects of power plant construction and operation on the recreational activities on Pigeon Lake; and 4) to solicit recommendations for improvement of the recreational value of Pigeon Lake.

Survey questionnaires were distributed to Port Sheldon residents as well as to fishermen on Pigeon Lake during a few days in late January 1980. The completed forms were mailed to our Fisheries Laboratory in Ann Arbor. Of the 75 questionnaires distributed, 42 were returned.

Results

The questionnaires were examined by question with the number of non-responses (no answer given) for each question counted. A few answers to some questions were inappropriate and were counted as non-responses. Answers for a few questions were grouped into categories and the percentage of responses in each of the categories was calculated (Tables 1-19).

At least 26 of the questionnaire participants had lived or vacationed in the general Pigeon Lake area for 20 yr or more (the average was 26 yr - Table 1). Four of the participants did not report their address, 19 reported their address to be in West Olive, and the others reported addresses in Holland, Hamilton, Grand Haven, Spring Lake, and Zeeland. Thus, respondents were divided between those in the immediate Pigeon Lake vicinity and those in more distant towns (Table 2).

Fishing appears to be the most popular form of recreation on the lake; of the 2583 times the respondents made recreation trips to Pigeon Lake, over half of them were for fishing, 35% for boating, 8% for swimming and 4% for other activites which included feeding birds and water skiing (Tables 3 and 4). One participant mentioned hunting and trapping in the Pigeon River - Pigeon Lake area but did not specify how many times during the year he went. Some smelt dipping in spring takes place at the mouth of Pigeon Lake (R. Lincoln, personal communication, MDNR, Grand Rapids, Mich.). Only two respondents stated they were not fishermen. It was not possible to determine if two other participants were anglers due to their non-response to some questions. One participant had not fished Pigeon Lake during 1979, but had fished it in previous years. Twenty-three of the respondents devoted at least half of their recreational Pigeon Lake trips to fishing. Fishing was stated as the most enjoyable form of recreation among the majority of respondents.

Pigeon Lake appears to be used most heavily during summer, but receives substantial use during winter for ice fishing (Table 5). Four participants specifically mentioned winter fishing for yellow perch in their questionnaires.

Recreationists use Pigeon Lake not only for its offerings, but also as a harbor and base for recreation on Lake Michigan. According to those responding to our survey, an average user travels on Pigeon Lake solely for Lake Michigan recreation 45% of the time. About 43% of the boat trips on Pigeon Lake are strictly for Pigeon Lake recreation and 12% of the trips are for recreation on both lakes (Table 6). Eight of the 42 participants in the questionnaire survey recreated only on Pigeon Lake, while only one participant always traveled Pigeon Lake just to reach Lake Michigan and to return from Lake Michigan and dock.

The average number of times the Michigan Department of Natural Resources (MDNR) access site was used per person per year by the 41 respondents was 6

Table 1. "How long have you lived in this area?" Survey conducted during winter-spring, 1980.

Statistic for responses	Years
Minimum	3
Maximum	80
Mean	26
Median	21
Mode	20
Number of respondents to question	40

Table 2. Address of survey participants. Survey conducted during winter-spring, 1980. There were 42 participants.

Address	Percentage of number of respondents
West Olive	50
Holland	29
Grand Haven	8
Spring Lake	5
Zeeland	5
Hamilton	3
Number of participants reporting address	38

Table 3. "Approximately how many times per year do you engage in the following activities on Pigeon Lake?" Survey conducted during winter-spring, 1980. There were 42 participants.

Activity	Percentage of total trips by respondents
Fishing	53
Boating	35
Swimming	8
Other (feeding birds, water skiing)	4
Total no. recreational trips reported	2583
Number of respondents to question	41

Table 4. "Which do you most enjoy on Pigeon Lake?" Survey conducted during winter-spring, 1980.

Activity	Percentage of number of responses
Fishing	53
Boating	24
Swimming	9
Sailing	7
Skiing	5
Other (living on shore)	2
Number of respondents to question	41

Table 5. "Of your recreational time spent on Pigeon Lake, what percentage is spent during the following seasons?" Survey conducted during winter-spring, 1980.

Season	Average percentage among respondents
Summer	41
Fall	12
Winter	28
Spring	19
Number of respondents to question	26

Table 6. "Of the times you use a boat on Pigeon Lake, What percentage is strictly for Lake Michigan recreation, strictly for Pigeon Lake recreation and for recreation on both lakes?" Survey conducted during winter-spring, 1980.

Location	Average Percentage among respondents
Pigeon Lake	43
Lake Michigan	45
Both	12
Number of respondents to question	31

Table 7. "Approximtately how many times per year do you use the MDNR public access site for Pigeon Lake?" Survey conducted during winter-spring, 1980.

Statistic for responses	Number of times used
Total	257
Minimum	0
Maximum	75
Mean	6
Median	2
Mode	0
Number of respondents	41

Table 8. "Would you like to see public access permitted onto the Consumers Power Company piers at the mouth of Pigeon Lake?" Survey conducted during winter-spring, 1980.

Response	Percentage of number of responses
Yes	74
No	26
Number of respondents to question	42

Table 9. "How long (years) have you fished on Pigeon Lake?" Survey conducted during winter-spring, 1980. There were 42 participants.

Statistic for responses	Years
Minimum	0
Maximum	60
Mean	18
Median	14
Modes	5, 20
Number of respondents to question	39

Table 10. "What fish do you most enjoy fishing for?" Survey conducted during winter-spring, 1980.

Preferred angling fish	Percentage of number of responses
Perch	28
Pike	20
Panfish	19
Salmon	12
Trout	12
Bass	6
Walleye	3
Number of respondents to question	39

Table 11. "Approximately how many of the following fish have you caught in Pigeon Lake during 1979?" Survey conducted during winter-spring 1980.

Fish caught	Total number caught
Perch	8605
Pike	134
Crappie	126
Largemouth bass	66
Trout	40
Salmon	40
Smallmouth bass	12
Number of respondents to question	34

Table 12. "When you catch fish, do you usually eat them, give them away, throw them back, use them for fertilizer or use them some other way?

Fish use	Percentage of number of responses
eat them	69
give them away	21
throw them back	10
other	0
Number of respondents to question	39

Table 13. "How would you rate the fishing on Pigeon Lake in comparison to other lakes in the area?" Survey conducted during winter-spring 1980.

Fishing quality	Percentage of number of respondents
Better	19
Average	43
Not as good	38
Number of respondents to question	37

Table 14. "From a fisherman's standpoint, have the numbers of the following fish increased, decreased or stayed the same since the barges and tugs have been harbored in Pigeon Lake?" Survey conducted during winter-spring 1980.

Fish affected	Percentage of number of respondents (total of 34 respondents)		
	Increased	Decreased	Same
Bass	3	26	17
Pike	3	35	35
Perch	24	24	41
Panfish	3	41	21
Salmon	24	15	12
Trout	26	12	12

Table 15. "Is your present fishing experience on Pigeon Lake more enjoyable than before the power plant was built, about the same as before the power plant was built or less enjoyable than before the power plant was built?" Survey conducted during winter-spring 1980.

Quality of fishing experience	Percentage of number of respondents
More enjoyable	21
Less enjoyable	50
Same	29
Number of respondents to question	14

Table 16. "Today (in your opinion), the present recreational value of Pigeon Lake is better than before the power plant was built, worse than before the power plant was built or the same as before the power plant was built?" Survey conducted during winter-spring, 1980. There were 42 participants.

Recreational value	Percentage of no. of respondents
Better	34
Worse	50
Same	16
No. of respondents to question	38

More Popular Reasons

Percentage of number of respondents

Better:	access to Lake Michigan by channel	21
	MDNR boat ramp	3
	piers at mouth of Pigeon Lake	3
Worse:	tugs and barges in Pigeon Lake taking up room for navigation and fishing	18
	blocking of beach area by barges	5
	unlighted buoys for barges (dangerous)	3
Same:	no comment	11
	number of people using lake is about the same	3

Table 17. "Name (if any) the bad or undesirable effects that you think the power plant has had on the recreational value of Pigeon Lake." Survey conducted during winter-spring, 1980.

More often cited effects	Percentage of no. respondents
Disruption of scenery	19
Ice on Pigeon Lake not safe because of open water to Lake Michigan (currents) and warm water circulation	13
None	13
Tugs and barges take up a lot of room	10
Too much commotion in Pigeon Lake from barges, tugs and construction	6
Power plant intake alters depth of Pigeon River	6
No beach or place to swim	6
Noise of construction	6
Number of respondents to question	31

Table 18. "Name (if any) the good or desirable effects that you think the power plant has had on the recreational value of Pigeon Lake." Survey conducted during winter-spring, 1980.

More often cited effects	Percentage of no. respondents
None	41
Construction and maintenance of channel between Lake Michigan and Pigeon Lake; Pigeon Lake a good harbor	26
Warm water circulated on north pier and discharge, good fishing near piers	11
Additional tax base for township	6
MDNR boat ramp	3
Number of respondents to question	34

Table 19. "What, in your opinion, could be done to improve the recreational value of Pigeon Lake?" Survey conducted during winter-spring, 1980.

More popular improvements	Percentage of no. respondents
Finish construction and remove equipment (including boats) from Pigeon Lake	14
Access to piers (at mouth of Pigeon Lake)	14
Control speed of power boats	8
More stocking of fish in Pigeon Lake	8
Restore beach for swimmers	6
Reduce numbers of carp	6
Number of respondents to question	36

while the median was 2 (Table 7). Sixteen of the participants did not use the access site at all, while a respondent from Holland used the boat ramp 75 times per year. Six participants used the site twice a year; once to launch the boat on the lake and once to remove the boat from the water before winter.

The participants fished an average of 18 yr on Pigeon Lake (Table 9). Of the three who did not respond to the question, two stated they were not fishermen. One respondent had not fished on Pigeon Lake at all, while each of three others had fished on Pigeon Lake for 60 yr. The participants enjoyed fishing most for yellow perch, followed by northern pike and then by panfish (includes centrarchids other than bass, i.e., bluegill, pumpkinseed, and crappie) (Table 10). Anglers answering the survey caught far more yellow perch than any other species; over 8600 yellow perch were reported caught during 1979 (Table 11). Over 20 participants reported catching 100 or more yellow perch during 1979. Yellow perch was followed by northern pike with a reported 134 caught and then by crappie (probably most were black crappie) with 126 reported caught. Note that some of these anglers may be including in their catch fish caught off the piers at the mouth of Pigeon Lake and probably fish caught in Pigeon River. Ten of the participants specifically mentioned fishing in the Pigeon River. Although not mentioned by survey anglers, Pigeon Lake also offers bullhead fishing (R. Lincoln, personal communication, MDNR, Grand Rapids, Mich.). Most participants usually eat the fish they catch, occasionally they give them away, and a few times fish are thrown back (Table 12).

A rough calculation of catch-per-angler-trip was made by dividing the total catch of each species of fish by the total number of trips reported by fishermen (1116). These calculations resulted in the following catch-per-angler-trip values: Yellow perch - 7.71, northern pike - 0.12, crappie - 0.11, largemouth bass - 0.06, trout - 0.04, salmon - 0.04, and smallmouth bass - 0.01. A comparable value for northern pike catch rates from one of Minnesota's best walleye - northern pike lakes (Winnibigoshish) in 1939 (Moyle et al. 1948) was 1.24 pounds/h which is considerably higher than values observed in Pigeon Lake (0.12 fish/trip). Another study (Hart 1940) of smallmouth bass in Algonquin Park, Ontario lakes showed that during 1937-1939 annual fishermen catches ranged from 0.025 lb/acre to 1.370 lb/acre. Smallmouth bass are uncommon in Pigeon Lake which accounts for their relatively low catch rate (0.01 fish/trip).

Most questionnaire participants (43%) believed Pigeon Lake to be an average to poor fishing lake compared with other lakes in the area (Table 13). However, some fishermen (19%) indicated Pigeon Lake was better than other lakes in the area due to relatively good perch fishing. Other reasons for the good fishing rating included access from Pigeon Lake to Lake Michigan and the Pigeon River and less pollution in Pigeon Lake than in other lakes in the area. Those who thought the fishing was not as good in Pigeon Lake than in other lakes in the area (38%) cited the general commotion from construction activity of barges and tugs as well as the relatively poor panfish fishing. Other reasons included too many power boats and overfishing.

Questionnaire responses regarding changes in game fish populations due to the use of Pigeon Lake as a harbor for tugs and barges were quite varied, but a few patterns emerged. The most striking was the belief that panfish populations have decreased in the lake since barges and tugs have harbored there (Table 14). All respondents except one believed that bass (*Micropterus*

spp.) and pike populations have decreased or remained about the same. Regarding yellow perch, 8 questionnaire answerers thought that the population had increased, 8 thought it had decreased, and 14 thought it had remained the same.

Half of the respondents answering the questionaire considered the present fishing experience on Pigeon Lake to be less enjoyable than before the power plant was built (Table 15). Three respondents indicated poorer fishing for bluegill as a reason, while two anglers thought that there were fewer fish in the lake in general. Other reasons included tugs and barges in the way of fishing spots and too many power boats on the lake. The three who thought their present fishing experience in the lake was more enjoyable after the plant was built either thought yellow perch fishing was better than before the plant was built or mentioned access to Lake Michigan as a reason. Those who thought this experience was the same gave no reasons for their choice.

Examining the general recreational value of Pigeon Lake before and after the power plant was built, we found half of the respondents to the questionaire thought the value to be worse now than before, about one-third thought the value better now than before, and the remainder answered that the value was the same (Table 16). Seven of those who thought the present value to be worse than before the plant was built cited the tugs and barges harbored in Pigeon Lake as the main cause, since they took room that could be used for navigation and fishing. Other reasons were related to the tugs and barges such as blocking of beach areas (two respondents), disruption of natural beauty (two), and unlighted buoys for barges (one); but also included a littering problem from visitors to Pigeon Lake on large recreation boats (one) and colder water (from Lake Michigan) (one). Those who thought the value was better now than before the plant was built cited access to Lake Michigan through the channel between the two lakes which is kept open (eight), the MDNR boat ramp (one) and the piers at the mouth of Pigeon Lake (one). Those who thought the value had remained the same gave no reasons (four) or pointed out that the number of people using the lake is the same both before and after plant operation (one).

The most often named undesirable effects of the power plant on the recreational value of Pigeon Lake are related to the tugs and barges harbored in Pigeon Lake (Table 17). Over a third (13 of 33) of the respondents to this question remarked about these vessels in some way: either barge movements being responsible for a decline in pike populations, blocking of the lake for other boat travel, creating a less scenic environment, causing traffic and noise, occupying too much room on the lake, eclipsing some beach and the swimming area, or buoys for tugs and barges not being lighted and therefore dangerous. Other undesirable effects of the power plant were: 1) that of weaker ice on a portion of the lake due to heated water which circulated along the north pier at the mouth of Pigeon Lake and discharged into the lake and, 2) the open channel to Lake Michigan and the resulting currents which prevent ice fishing in some spots at times. Other unwanted effects noted were smoke from chimneys of the plant, effluent from ash ponds entering Pigeon Lake, more noise on roads near the lake, strobe lights on plant chimneys, colder water, and increased boat traffic (including boat speeders).

Of the 34 respondents naming the good or desirable effects the power plant had on recreational value of Pigeon Lake, 13 replied that there were no desirable effects; 10 of those 13 reported a West Olive address (Table 18). Nine participants cited the channel between Lake Michigan and Pigeon Lake and

the accompanying good harbor as a desirable effect. Other desirable effects named included: hot water circulated in the pipe at the north pier when discharged in winter attracts fish which results in good fishing near the piers (8), the plant providing an additional tax base for Port Sheldon Township (2), and the power company leasing the land for the MDNR boat access on Pigeon Lake (1).

The more popular suggested improvements include access for fishing off the piers at the mouth of Pigeon Lake (four of the five suggesting access to piers were not West Olive residents), more fish stocking, finish construction work and remove tugs and barges from Pigeon Lake, control speed of power boats, and prohibit water skiing entirely or restrict to under 3 m the size of boats for water skiing (Table 19). Other suggested improvements included reducing number of trash fish (carp) (2), keeping the channel open (1), stopping the ash pond overflows into Pigeon Lake (1), stopping use of the channel connecting Pigeon Lake to Lake Michigan for intake water for the power plant (1), enforcing no wake and safety laws (1), and better enforcement of game laws (1). The stocking of walleyes in Pigeon Lake was suggested by three participants; two participants suggested panfish, trout, and salmon stocking; and one participant mentioned stocking of northern pike.

Summary

Survey results may be biased concerning questions on general recreational use since the questionnaires were distributed to recreationists on the lake during January. All surveyed were fishermen, therefore boaters, and particularly swimmers and water skiers, may not be as well represented as they should have been. Note, though, that Port Sheldon residents also participated in the survey. Most of the participants have lived in the area for at least 5 yr and on the average for 20 yr. The group of fishermen participating in the survey may well represent the population of fishermen on the lake. Most respondents have been fishing on Pigeon Lake for 5 yr or more and half of the fishermen in the survey have fished on the lake for 15 yr or more. The response rate for the questionnaire was relatively good; 42 of 75 distributed or 56% were returned.

Fishing appears to be the dominant form of recreation on the lake; hours spent fishing may be close to half the total recreation hours on the lake. Boating is another important recreational activity on Pigeon Lake, while swimming, sailing, and water skiing are not enjoyed as much as fishing or boating. Recreationists use the lake most heavily during summer, but there is a substantial use of the lake during winter by fishermen. Many recreationists use Pigeon Lake as a harbor for boats which are subsequently used for Lake Michigan recreation.

More yellow perch are caught by anglers in Pigeon Lake than other game species with northern pike being the second-most often caught species. Yellow perch, trout, and salmon fishing grounds include the area between the piers (in Lake Michigan at the mouth of Pigeon Lake) and the Pigeon River. Most fish are eaten (69%), but some are given away and some thrown back. Pigeon Lake is probably an average to slightly below average fishing lake in the area; it may be better than other lakes for yellow perch fishing, but not as good for panfish (Centrarchidae other than bass).

Panfish populations, most notably the bluegill population, in the lake and

river have apparently declined in recent years; reasons for the decline are not known. Anglers in this survey as well as MDNR creel census surveys indicate a substantial bluegill fishery in Pigeon Lake during the 1950s. Largemouth bass populations may also be on the decline; such a decrease was observed from 1977 to 1978. Perhaps competition from other predators or angling mortality have caused this decline. The northern pike population in the lake was stable between 1977 and 1978 (Jude et al. 1980), however not enough were caught in 1979 to determine population size. Pike populations may have declined in 1979-1980 due to dredging of vegetation from prime habitat, barges continuing to occupy part of the preferred water for this species, and illegal gillnetting. The adult yellow perch population appeared to be stable, but possibly stunted from 1977 through 1979 (Jude et al. 1980). The 1979 year class was exceptionally large.

Recreationists consider the general commotion of barges and tugs and their occupation of space on the lake to have a major undesirable effect on the recreational value of Pigeon Lake. Tugs and barges hinder boat transit, detract from lake scenery, occupy a good portion of the lake surface including beach zone and swimming areas, and add noise and traffic to the lake.

Most recreationists recognize the construction and maintenance of the channel between Lake Michigan and Pigeon Lake as the main benefit of the construction and operation of the J.H. Campbell Plant. The channel allows recreationists to travel between the two lakes, with Pigeon Lake serving as a safe harbor. Good fishing near the recently constructed piers in summer (due to riprap) and winter (due to attraction of fish to warm water circulated along the north pier) is another desirable effect.

Completion of construction of the offshore discharge and intake structures and removal of barges, tugs, and construction equipment will improve the recreational value of Pigeon Lake. Maintaining the channel between Lake Michigan and Pigeon Lake is also important in maintaining the high recreational value of Pigeon Lake.

BASIN MORPHOLOGY

The Pigeon River flows into the east basin of Pigeon Lake, which in form appears similar to the many meander bends occurring along the river's length. The central river channel defined by the 2-m contour (Appendix 1) passes through the east basin. The remaining area of the east basin is of nearly uniform depth (approximately 1 m) and slopes gradually downward toward the river channel.

The central basin, extending west to the 4-m contour, is where the central river channel begins to widen and becomes less distinct. Like the east basin, most of the central basin is less than 2 m in depth.

The transition zone from central to west basins is quite dramatic as evidenced by the abrupt change in depth from 2 to 7 m along the northern portion. To the south, the central river channel gradually deepens as it enters the west basin and reaches a maximum depth of 8.25 m. Unlike the central and east basins, the west basin is partially rimmed by steep dropoffs, making most of this region of the lake greater than 6 m. The western end of Pigeon Lake narrows as the basin continues west into Lake Michigan.

PHYSICAL AND CHEMICAL CHARACTERISTICS

Water Temperature

Water temperatures in the central basin were higher than in the west basin during both June and September and no thermal stratification was evident at either station. On 3 June 1980, Lake Michigan surface waters in the vicinity of Pigeon Lake at 3 and 6 m were 15.0 C and 14.3 C, respectively, which were comparable to water temperatures measured in the west basin of Pigeon Lake the same day (Table 20). The June bottom temperature at the intake canal (see Fig. 2) was identical to the bottom temperature in the west basin, however surface values were slightly different. The thermal regime of the water column near the intake canal appears most similar to that of the west basin, that basin nearest Lake Michigan.

Secchi Disc

Secchi disc readings for the west and central basins were considerably different at both sampling times. The June sampling was preceeded by several days of heavy rainfall which could account for the exceedingly low Secchi disc readings in the central basin (0.25 m) when compared with the west basin (1.0 m) (Table 20). Surface water Secchi disc readings at the intake canal were also low, which is an indication of a flow of surface water from the central basin through the canal. Water flows from Pigeon Lake through the intake canal only when drawn by the J.H. Campbell Power Plant; otherwise no flow would be expected. Plant personnel (J. Kruger, personal communication, Consumers Power Co., West Olive, Mich.) verified that cooling water was being drawn through the intake channel during the June 1980 sampling period. However, Consumers Power Company (1975) did not indicate whether the power plant was drawing water at the time of the September 1972 sampling. Therefore, September 1972 Secchi disc measurements may represent 'no-flow' conditions which cause surface water at the intake canal station to most likely resemble conditions in the west basin.

Dissolved Oxygen

Saturation levels of oxygen were present throughout the water column at the Lake Michigan-influenced west basin station in both June and September (Table 20). However, dissolved oxygen values for the central basin station were considerably lower than 100% saturation levels (9.5 mg/L at 16.5 C). Highly turbid surface waters as indicated by low Secchi disc readings, could account for the low June dissolved oxygen concentrations. Unlike the uniformity observed in the west and central basins, June dissolved oxygen measurements at the intake canal station indicated chemical stratification of the water column.

pH

Like most surface waters of Michigan inland lakes, pH for Pigeon Lake was slightly alkaline, ranging from 6.9 to 8.5 (Table 20). The pH readings at the intake canal station were intermediate between the more alkaline west basin and Pigeon River-influenced central basin.

Table 20. Physical and chemical parameters measured in the central basin, west basin, and intake canal of Pigeon Lake, Ottawa County, Michigan, September 1975 and June 1980.

Station	Date	Depth (m)	Temperature (C)	Secchi Disc (m)	Dissolved Oxygen (mg/L)	pH	Total Alkalinity as $CaCO_3$ (mg/L)	Hardness as $CaCO_3$ (mg/L)	Nitrate NO_2&NO_3-N (mg/L)	Ammonia NH_3-N (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorous (mg/L)	Ortho-phosphate (mg/L)	Chloride (mg/L)
Central Basin	3 Jun	surface 0.5	19.5(16.5*)	0.25*	6.0*	7.9	105	156	0.657	0.059	2.411	0.207	0.014	13.173
		bottom 2.5	19.5(16.5*)		5.8*	7.9	105	157	0.674	0.061	2.698	0.251	0.015	13.187
	13 Sep#	surface 0.0	18.5	2.45	6.0	7.20	100	170	-	-	-	-	-	-
		bottom 3.5	18.4		6.0	6.90	110	160	-	-	-	-	-	-
Intake	3 Jun	surface 0.5	16.5(16.5*)	0.25*	7.2*	8.2	112	146	0.348	0.023	1.495	0.097	0.004	14.126
		mid-depth 2.0	15.5(14.3*)		7.9*	8.1	113	146	0.340	0.037	1.668	0.103	0.004	15.270
		bottom 4.5	15.0(13.8*)		9.2*	8.2	113	144	0.270	0.021	1.348	0.077	0.003	10.221
	13 Sep#	surface 0.0	17.8	1.65	10.0	8.10	110	120	-	-	-	-	-	-
		mid-depth 3.0	17.8		10.0	8.20	110	150	-	-	-	-	-	-
		bottom 8.1	15.0		10.0	8.25	120	140	-	-	-	-	-	-
West Basin	3 Jun	surface 0.5	15.3(15.0*)	1.00*	10.0*	8.3	115	141	0.258	0.015	1.138	0.056	0.002	10.634
		mid-depth 4.0	15.0(13.9*)		10.0*	8.5	114	140	0.237	0.011	1.154	0.064	0.001	11.205
		bottom 7.5	15.0(13.6*)		9.7*	8.5	114	143	0.231	0.012	1.163	0.073	0.001	11.581
	13 Sep#	surface 0.0	17.8	1.65	10.0	8.35	120	135	-	-	-	-	-	-
		mid-depth 2.0	17.8		10.0	8.35	115	120	-	-	-	-	-	-
		bottom 8.0	17.0		9.0	8.10	110	130	-	-	-	-	-	-

* Samples collected 9 June 1980.

Data from Consumers Power Company (1975).

Total Alkalinity and Hardness

Total alkalinity and hardness were both expressed as mg/L calcium carbonate. Consistent with trends observed for other chemical and physical parameters, waters in the region of the intake canal were intermediate in total alkalinity and hardness (Table 20) compared with the west and central basins, but most resembled water from the Pigeon River-influenced central basin. The Lake Michigan-influenced west basin was higher in hardness and lower in total alkalinity than the Pigeon River-influenced central basin. Surface runoff, contributing to the dissolved ion concentration of the Pigeon River, would be expected to increase the alkalinity of central basin waters, while the west basin should remain relatively constant. Hardness should be influenced in the same manner; however, the opposite trend was observed. At the Lake Michigan-influenced station hardness values ranged from 156-170 mg/L which were considerably higher than values (110-120 mg/L) measured at the intake and central basin stations. We have no explanation for this apparent anomaly. These data do suggest that on 3 June and 13 September most water used for cooling the plant's condensers originated from the Pigeon River.

Phosphorus

Although essential for the survival of aquatic organisms, phosphorus is the least abundant of all major nutritional compounds in aquatic systems and thus generally limits biological productivity. Total phosphorus is a measure of all forms of the element, both organic and inorganic, and any particulates in solution. Vollenweider (as cited in Wetzel 1975) demonstrated that the amount of total phosphorus increased with lake productivity; eutrophic lakes ranged in concentration from 0.03 to 1.10 mg/L total phosphorus.

From total phosphorus concentrations (Table 20, Fig. 5), the central basin of Pigeon Lake would appear to be more productive than the west basin. However, total phosphorus values for the west basin were sufficiently high to consider that region of Pigeon Lake eutrophic. Schelske et al. (1980) reported that total phosphorus in the nearshore waters of Lake Michigan ranged seasonally from 0.015 to 0.150 mg/L, while offshore water remained between 0.005 and 0.010 mg/L. The high variability in Lake Michigan nearshore values was attributed partially to enrichment from the many tributaries flowing into the lake. Therefore, the Lake Michigan-influenced west basin of Pigeon Lake would be expected to vary greatly in its total phosphorus content and may not accurately reflect the productivity of that region of the lake at any given time.

Orthophosphate is an inorganic, soluble form of phosphorus that is generally found in concentrations significantly lower than total phosphorus since orthophosphorus is readily taken up by aquatic plants and algae. Orthophosphate enters a lake via tributaries from land runoff, is regenerated from anoxic sediments and is released to the water by aquatic vegetation. Thus it is not surprising that the Pigeon River-influenced central basin, supporting a dense growth of aquatic plants, is higher in orthophosphate than the west basin.

Nitrogen

Nitrogen, like phosphorus, is essential for all aquatic life forms. It is abundant in nature but can limit the biological productivity of lakes. Of the forms analyzed, ammonia is perhaps the most useful for assessing the "condition" of lotic systems. Generated primarily as a result of bacterial decomposition in lake sediments, ammonia, when encountered in surface waters, is sometimes accepted as chemical evidence of sanitary pollution (American Public Health Association 1971). Concentrations of ammonia in Pigeon Lake did not exceed 0.065 mg/L. Consistent with temperature and dissolved oxygen data, ammonia concentrations varied little throughout the water column in the west and central basins. This condition is most likely the result of inflowing Lake Michigan and Pigeon River water mixing the water column sufficiently to prevent stratification which would otherwise be expected to occur by June.

Nitrate is a form of nitrogen that is directly assimilated by algae and higher aquatic plants. The ratio of nitrate to ammonia in lake water varies greatly according to the allochthonous sources of both compounds. In drainage areas containing calcareous sedimentary landforms, unpolluted lakes can have nitrate/ammonia (NO_3-N: NH_3-N) ratios of 25:1 (Wetzel 1975). However, ratios approach 1:1 in regions where the input of nitrate is low, and when influenced by an agricultural application of nitrogen fertilizers or slight sewage contamination, ratios near 1:10 are common (Wetzel 1975). The averages of surface, mid-depth, and bottom nitrate ammonia ratios for the central basin, intake canal, and west basin station were calculated to be: 11.1:1, 12.4:1 and 19.3:1 respectively. By comparison, Pigeon Lake appears relatively unpolluted.

Total kjeldahl nitrogen is the sum of free-ammonia and of all organic nitrogen compounds occurring in lake waters. The organic component of this parameter is contributed by nitrogen containing biomolecules such as amino acids, polypeptides and protein. As expected, total kjeldahl nitrogen values in the more productive central basin were higher than values for the west basin.

Chloride

Chloride is one of the most abundant anions (negative ion) found in surface waters. Natural sources of chloride within the drainage basin include weathering and erosion of rocks and soil. Domestic and some industrial effluents, when present, also contribute to chloride loading. For instance kitchen waste and commercial and small manufacturing sewage averaged 40-80 mg chloride/liter, depending on per capita consumption (O'Connor and Mueller 1970). Chloride as sodium chloride, used in many counties during winter as a deicer, may enter lakes and streams in the spring following snowmelt.

Numerous investigators have reported chloride concentrations for Lake Michigan over the past 20 yr. Copeland and Ayers (1972) sampled water at 23 locations throughout Lake Michigan and arrived at an average inshore and offshore chloride concentration of 11 mg/L with a range of 9.1 to 14.5 mg/L. This average is comparable to chloride concentrations found in the Lake Michigan-influenced west basin of Pigeon Lake and bottom waters in the vicinity of the intake canal (Table 20, Fig. 5). As would be expected, chloride concentrations in the Pigeon River-influenced central basin were higher than in Lake Michigan and the west basin. However, surface and mid-depth concentrations at the intake station (14.126 and 15.270 mg Cl/L) were the

highest recorded in Pigeon Lake, exceeding levels in the central basin. This occurrence would seem to indicate an input of chloride in the vicinity of the intake canal, possibly related to Lake Michigan dredging operations headquartered in the west basin of Pigeon Lake.

Lake Comparisons

Four lakes were selected for limnological comparison (Fig. 6) with Pigeon Lake. These lakes receive inflows from tributaries of Lake Michigan's southern basin. Mona Lake (281 ha - Fig. 7) and Muskegon Lake (1680 ha - Fig. 8), both in Muskegon County, lie north of Pigeon Lake as does Stony Lake (113 ha - Fig. 9), located in Oceana County. Lake Macatawa (721 ha - Fig. 10) is located south of Pigeon Lake in Ottawa County (Fig. 11). Recall for comparison that Pigeon Lake proper is about 36 ha (Appendix 1). Data for three of the lakes, Macatawa, Mona, and Muskegon (Tables 21, 22, and 23), were taken from the 1975 National Eutrophication Survey conducted by the Environmental Protection Agency (Environmental Protection Agency 1975a, 1975b, 1975c) in 1972. Physical and chemical data for Stony Lake were collected by the Michigan Department of Natural Resources and obtained via the Storet retrieval system (Table 24).

It was concluded by EPA that Lakes Macatawa, Mona, and Muskegon were eutrophic. All three lakes were found to have average total phosphorus levels for both June and September 1972 well above the minimum 0.03 mg/L (refer to RESULTS - Phosphorus in PHYSICAL AND CHEMICAL CHARACTERISTICS section) throughout the water column (Fig. 6, Tables 21, 22, and 23). The clinograde oxygen profiles for these lakes (no or very low dissolved oxygen on the bottom) are characteristic of a eutrophic condition. There was no depletion of dissolved oxygen in the hypolimnion of Pigeon Lake. Ammonia, as would be expected, generated primarily as a result of bacterial decomposition in lake sediments, reached high levels in bottom samples from the lakes in the EPA study. Surface waters of Lake Macatawa in June 1972 contained a surprisingly high (1.50 mg/L) ammonia concentration at station 01 (see Fig. 6) with a lake average of 1.09 mg/L (Table 21). In high concentrations such as these, ammonia can be harmful to aquatic life. The acute toxicity of ammonia to bluegill, bass, and channel catfish expressed as a 96-h LC_{50} (toxicant concentration at which 50% of the specimens die after 96 h of exposure) in hard water (250-350 mg $CaCO_3$/L hardness) at 22 C and pH of 8 is 0.40-0.80 mg/L, 0.72 mg/L, and 1.50 mg/L respectively (Rosebloom and Richey 1977). Furthermore, the authors suggested that for the protection of fishes, ammonia should not exceed 0.04 mg/L in Illinois streams. When encountered in surface waters ammonia can be taken as chemical evidence of sanitary pollution (American Public Health Association 1971).

As natural collecting basins for Lake Michigan tributaries, Lakes Macatawa, Mona, and Muskegon receive a continual nutrient load. Tributaries accounted for 68%, 52%, and 90% of the annual nutrient load (total phosphorus and nitrogen) for Macatawa, Mona, and Muskegon respectively in 1972 (Environmental Protection Agency 1975a, 1975b, 1975c). Known municipal sewage treatment plant effluents comprised 21%, 34%, and 8% of the nutrient input for these lakes. Industrial sources of input, known to occur for Lake Macatawa and Muskegon Lake, were not addressed by the Eutrophication Survey. Considering mean hydraulic retention times of 77, 76, and 23 days, net nutrient accumulations of phosphorus and nitrogen combined were 227,518 kg for Lake Macatawa, 41,709 kg for Lake Mona, and 75,196 kg for Muskegon Lake. Based on lake volumes of 21,360 acre-feet, 9313 acre-feet, and 97,525 acre-feet, net

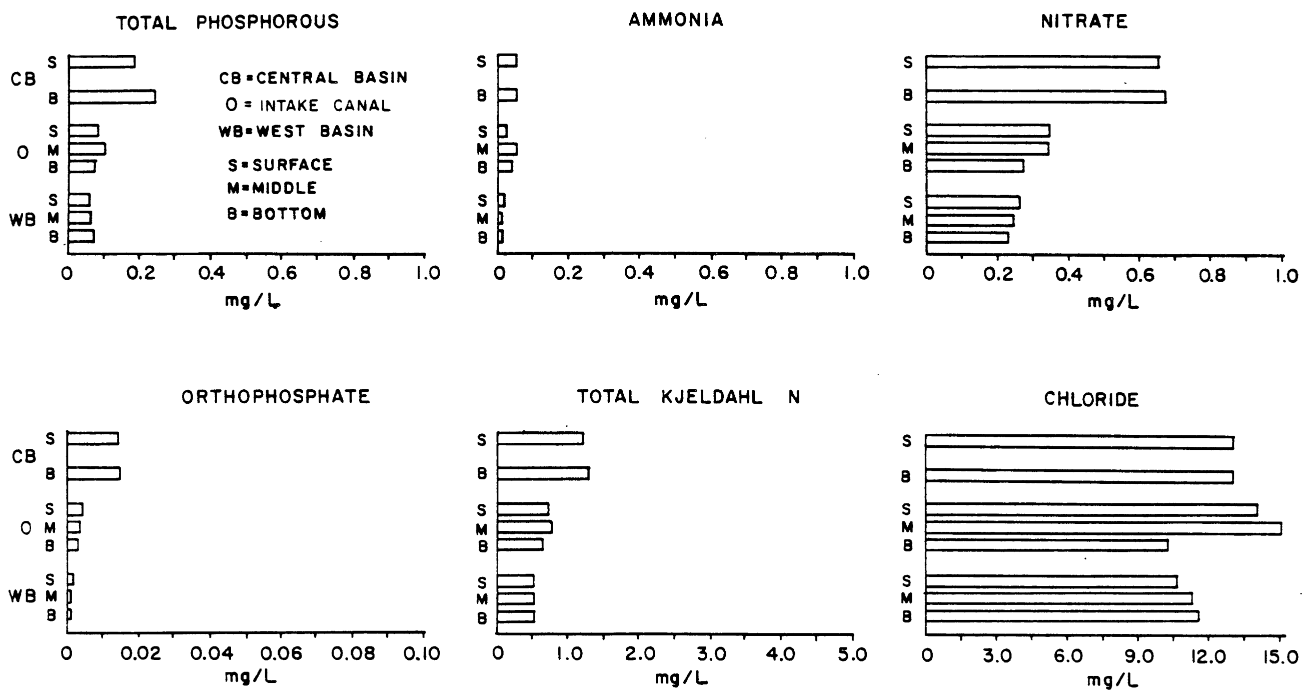

Fig. 5. Concentrations of phosphorous and nitrogen compounds and chloride ion in the intake canal, west basin and central basin of Pigeon Lake, June 1980.

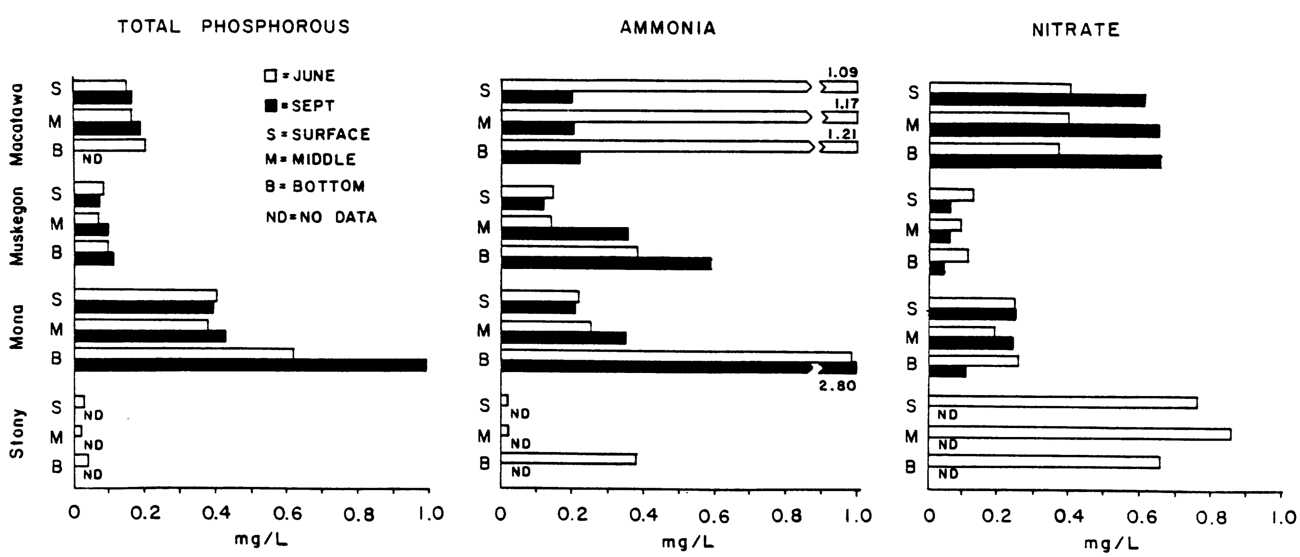

Fig. 6. Comparison of mean total phosphorous, ammonia and nitrate concentrations for Lakes Macatawa, Muskegon, Mona (1972 data), and Stony (1975 data).

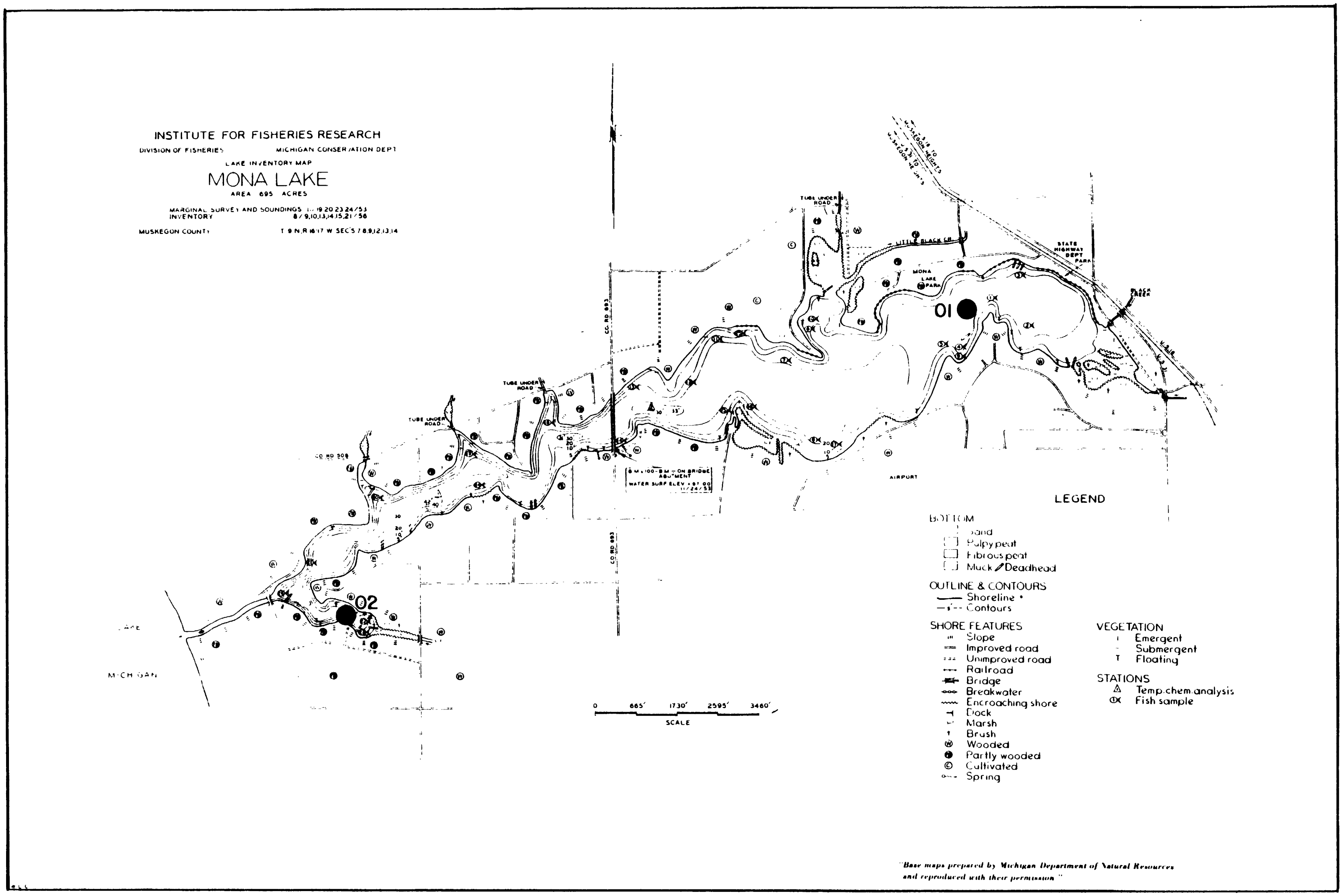

Fig. 7. Hydrographic map of Mona Lake showing water sampling stations 01 and 02. (From MDNR files).

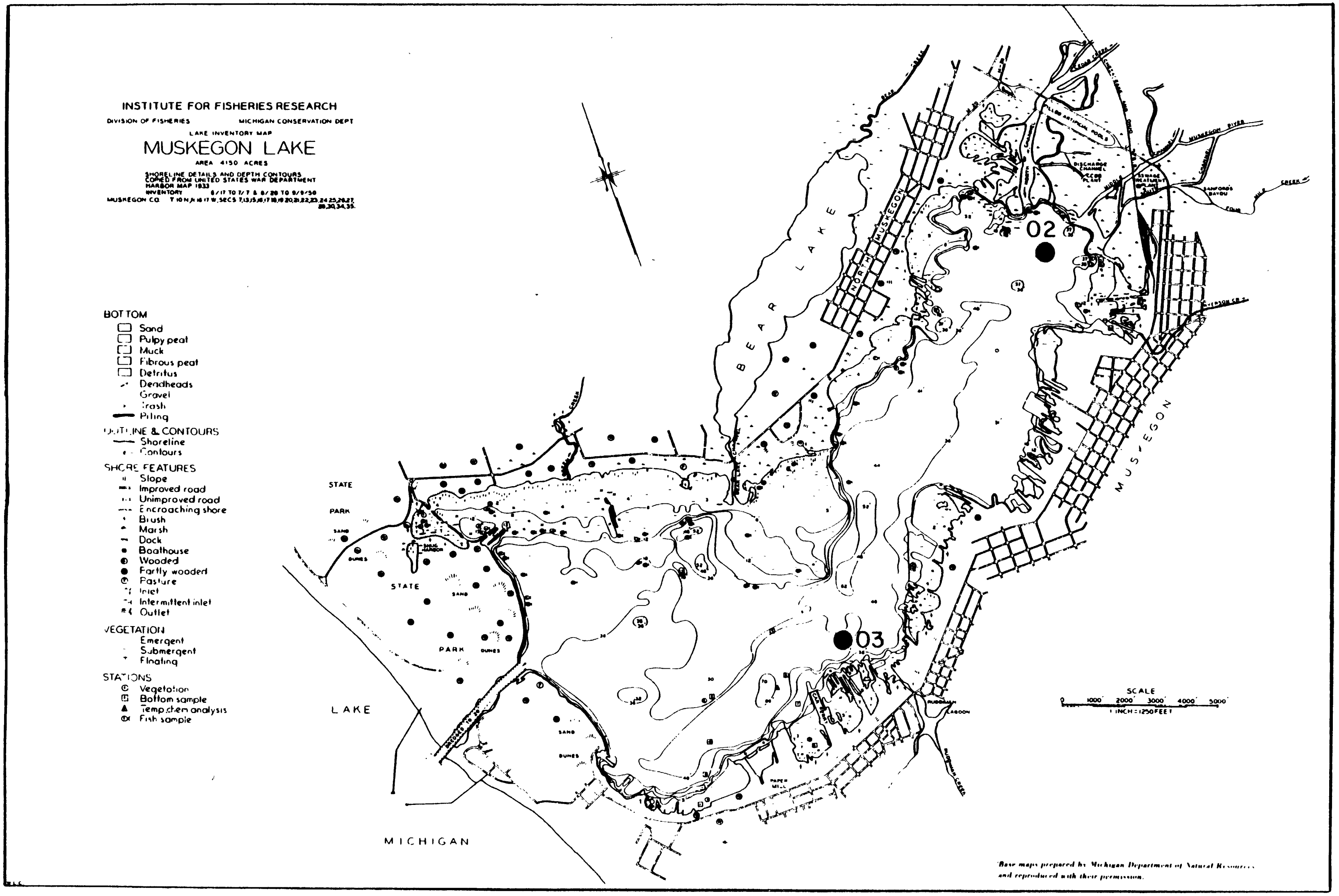

Fig. 8. Hydrographic map of Muskegon Lake showing water sampling stations 02 and 03. (From MDNR files).

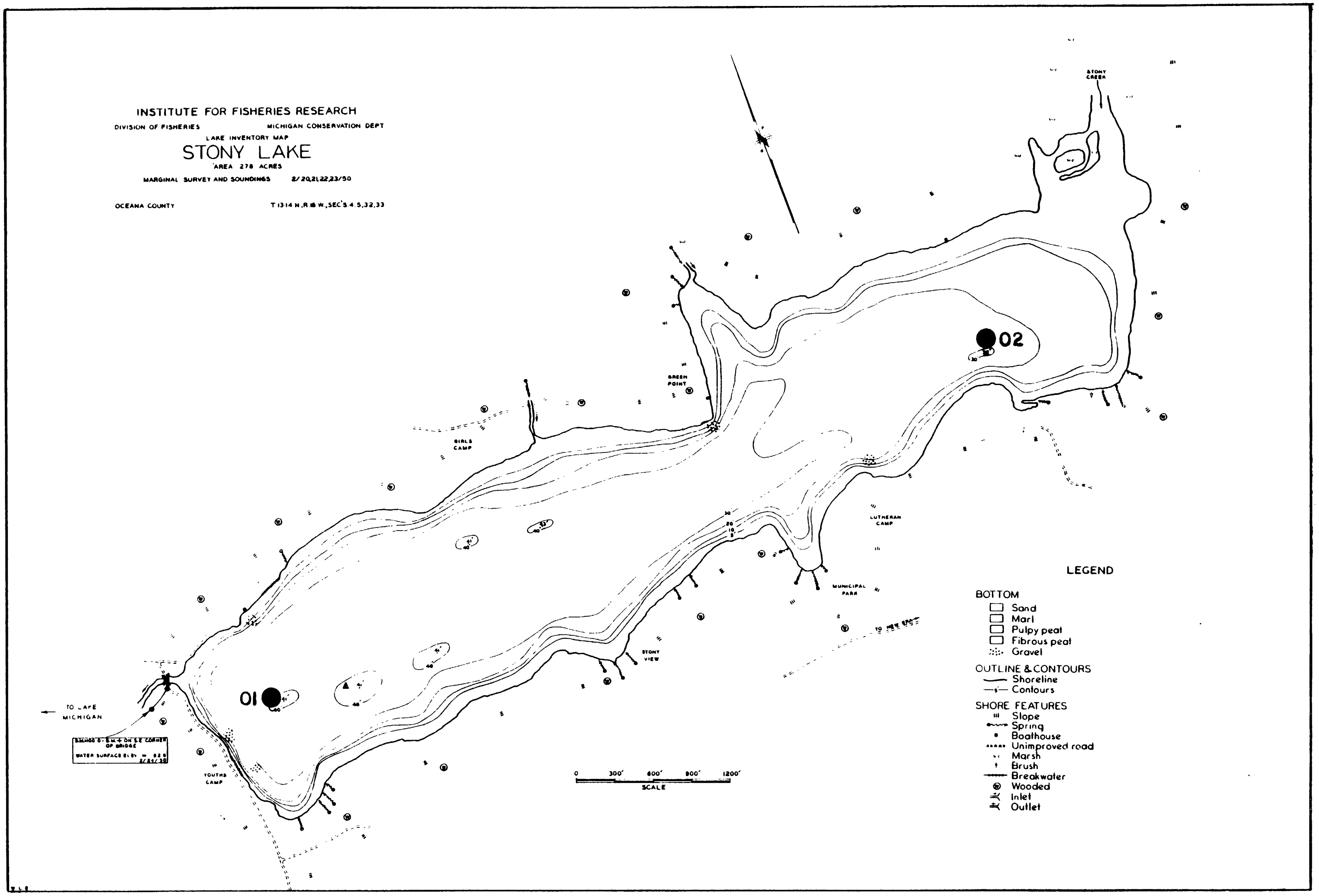

Fig. 9. Hydrographic map of Stony Lake showing water sampling stations 01 and 02. (From MDNR files).

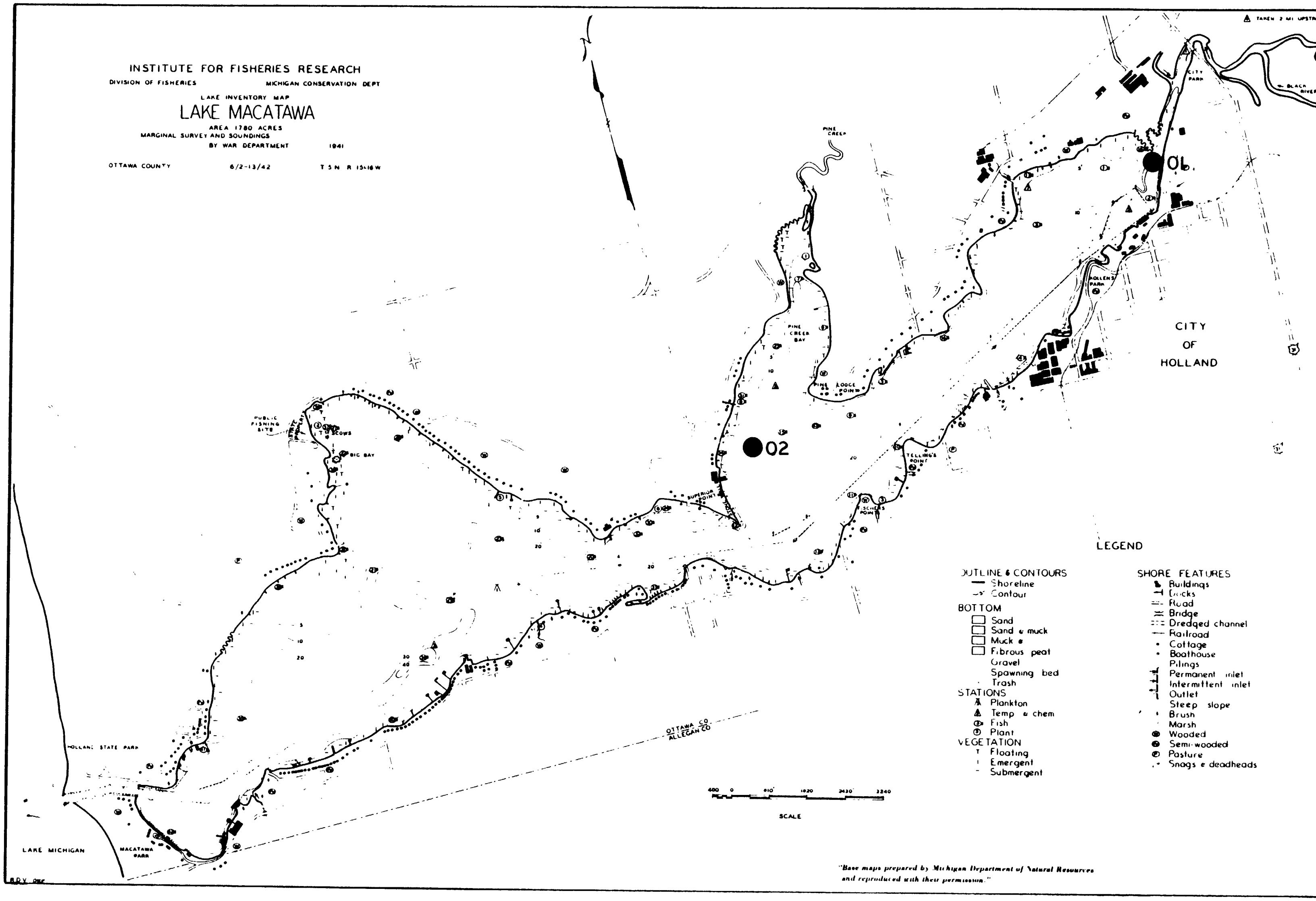

Fig. 10. Hydrographic map of Lake Macatawa showing water sampling stations 01 and 02. (From MDNR files).

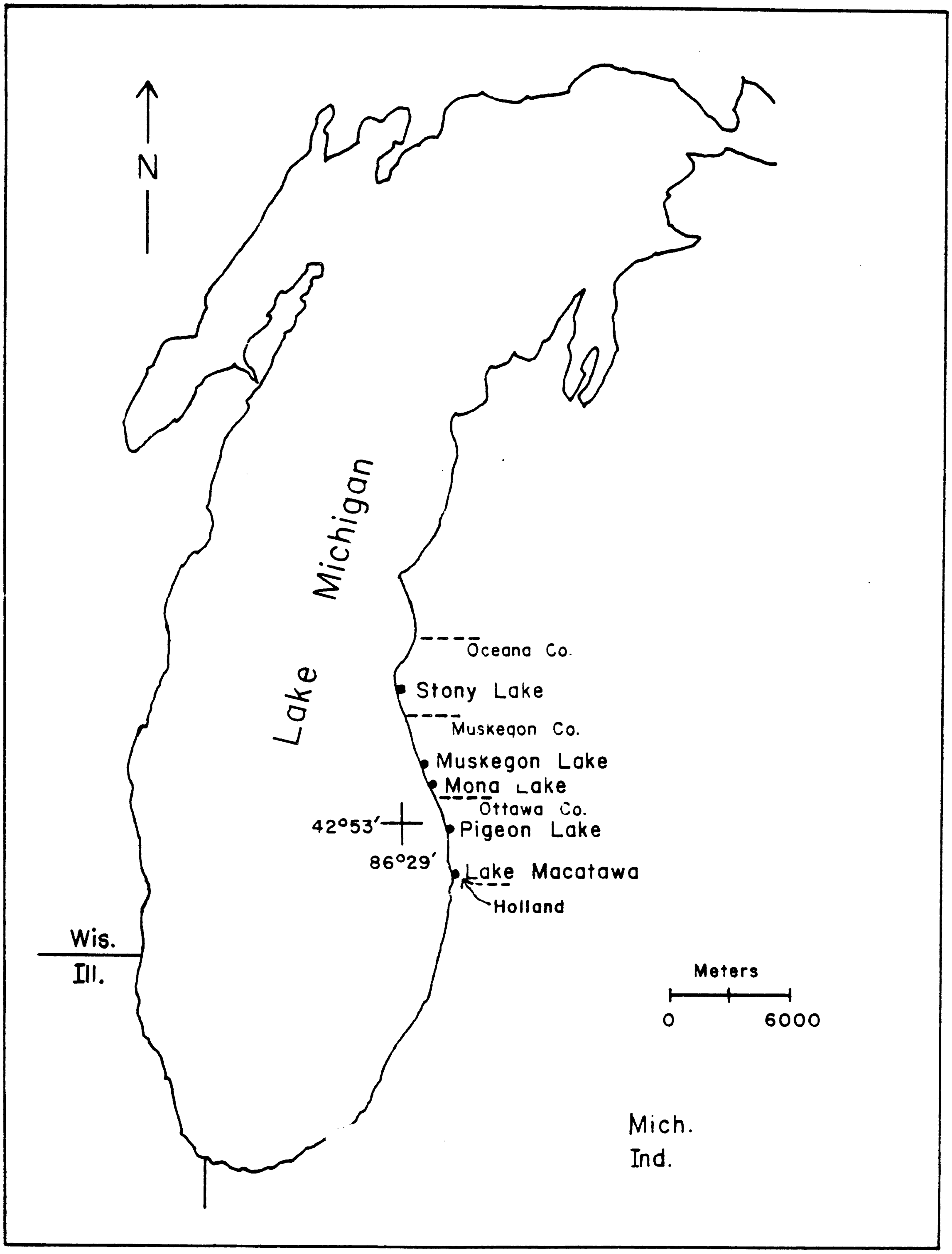

Fig. 11. Map showing proximity of Pigeon Lake to Lakes Macatawa, Muskegon, Mona and Stony along the eastern shore of Lake Michigan.

Table 21. Physical and chemical parameters measured at two stations in the east basin of Lake Macatawa, Ottawa County, Michigan, in June and September 1972. (From EPA 1975a).

Station	Date	Depth (m)		Water Temperature (C)	Secchi disc (m)	Dissolved Oxygen (mg/L)	pH	Total Alkalinity as $CaCO_3$ (mg/L)	Nitrate NO_2&NO_3-N (mg/L)	Ammonia NH_3-N (mg/L)	Total Phosphorous (mg/L)
02	14 Jun	surface	0.00	22.00	0.61	7.5	7.80	136	0.380	0.680	0.124
		mid-depth	4.57	18.9		4.9	7.55	139	0.380	0.940	0.136
		bottom	6.10	18.5		4.0	7.50	139	0.350	0.920	0.143
	18 Sep	surface	0.00	-	-	-	-	117	0.230	0.150	0.142
		mid-depth	1.22	-		-	-	122	0.230	0.160	0.137
		bottom	4.57	-		-	-	121	0.240	0.190	0.117
01	14 Jun	surface	0.00	23.1	0.25	4.8	7.50	158	0.410	1.500	0.140
		mid-depth	4.57	22.5		4.2	7.40	163	0.400	1.400	0.162
		bottom	6.40	21.9		2.8	7.45	165	0.400	1.500	0.253
	18 Sep	surface	0.00	-	-	-	-	132	0.980	0.250	0.177
		mid-depth	3.05	-		-	-	132	1.040	0.240	0.177
		bottom	4.57	-		-	-	133	1.060	0.250	0.219
Mean values for stations 02 and 01 combined	14 Jun	surface							0.395	1.090	0.132
		mid-depth							0.390	1.170	0.149
		bottom							0.375	1.210	0.198
	18 Sep	surface							0.605	0.200	0.137
		mid-depth							0.635	0.200	0.157
		bottom							0.650	0.220	0.168

Table 22. Physical and chemical parameters measured in the east and west basins of Mona Lake, Muskegon County, Michigan, June and September 1972. (From EPA 1975b).

Station	Date	Depth (m)		Water Temperature (C)	Secchi disc (m)	Dissolved Oxygen (mg/L)	pH	Total Alkalinity as $CaCO_3$ (mg/L)	Nitrate NO_2&NO_3-N (mg/L)	Ammonia NH_3-N (mg/L)	Total Phosphorous (mg/L)
01	13 Jun	surface	0.0	19.7	1.0	9.0	9.30	114	0.310	0.260	0.438
		bottom	5.5	17.7		4.2	8.95	120	0.250	0.980	0.620
	9 Sep	surface	0.0	-	1.5	-	9.00	112	0.260	0.200	0.341
		mid-depth	4.5	19.8		6.8	8.80	113	0.270	0.400	0.416
		bottom	6.0	19.3		4.7	8.18	118	0.150	1.240	0.570
02	13 Jun	surface	0.0	20.0	1.0	8.6	9.30	115	0.180	0.190	0.378
		mid-depth	3.0	18.4		7.6	9.40	116	0.190	0.260	0.369
	9 Sep	surface	0.0	-	1.5	-	8.90	116	0.230	0.220	0.426
		mid-depth	4.5	19.9		6.9	8.85	114	0.210	0.310	0.442
		bottom	9.5	17.3		0.0	7.70	130	0.050	4.360	1.420
Mean values for stations 01 and 02 combined	13 Jun	surface							0.245*	0.225*	0.408*
		mid-depth							0.190#	0.260#	0.369#
		bottom							0.250#	0.980#	0.620#
	9 Sep	surface							0.245	0.210	0.384
		mid-depth							0.240	0.355	0.429
		bottom							0.100	2.800	0.995

* Single value obtained from station 02.
# Single value obtained from station 01.

Table 23. Physical and chemical parameters measured in the east and central basins of Muskegon Lake, Muskegon County, Michigan, June and September 1972. (From EPA 1975c).

Station	Date	Depth	(m)	Water Temperature (C)	Secchi disc (m)	Dissolved Oxygen (mg/L)	pH	Total Alkalinity as $CaCO_3$ (mg/L)	Nitrate NO_2&NO_3-N (mg/L)	Ammonia NH_3-N (mg/L)	Total Phosphorous (mg/L)
03	13 Jun	surface	0.00	19.6	1.68	9.0	8.30	128	0.140	0.140	0.064
		mid-depth	9.14	16.1		-	7.95	125	0.060	0.150	0.052
	19 Sep	surface	0.00	-	1.52	-	8.25	128	0.030	0.060	0.051
		mid-depth	10.67	19.4		1.8	7.63	125	0.040	0.490	0.089
		bottom	17.98	14.2		0.4	7.50	123	0.030	0.900	0.149
02	13 Jun	surface	0.00	21.2	1.52	8.0	8.10	129	0.110	0.160	0.079
		mid-depth	4.57	18.5		7.4	8.10	127	0.100	0.150	0.080
		bottom	7.62	15.6		3.6	7.85	128	0.110	0.380	0.089
	19 Sep	surface	0.00	-	1.52	-	8.00	132	0.070	0.180	0.079
		mid-depth	4.57	20.0		5.9	8.00	131	0.060	0.170	0.087
		bottom	9.45	19.1		4.3	7.80	133	0.040	0.280	0.071
Mean values for stations 03 and 02 combined	13 Jun	surface							0.125	0.150	0.072
		mid-depth							0.080	0.150	0.066
		bottom							0.110*	0.380*	0.089*
	19 Sep	surface							0.050	0.120	0.065
		mid-depth							0.050	0.330	0.088
		bottom							0.035	0.590	0.110

* Single value obtained from station 02.

nutrient accumulations represent concentrations of 23.43, 9.85, and 1.70 lb of nutrients/acre-foot. Thus the eutrophic condition of these three lakes is not surprising.

In terms of total phosphorus levels Stony Lake would appear marginally eutrophic (Table 24) (refer to RESULTS - Phosphorus in PHYSICAL AND CHEMICAL CHARACTERISTICS section). Elevated ammonia concentrations in the tropholytic zone, indicative of productive lakes, were most likely preserved by thermal stratification. This condition would prevent mixing of epilimnetic and hypolimnetic waters, thereby limiting to the tropholytic zone the distribution of ammonia which was generated by bacterial decomposition in lake sediments. The clinograde oxygen profile, as indicated by dissolved oxygen measurements, was unusual in that dissolved oxygen values for surface samples were exceptionally low. The chemical data suggest that Stony Lake was by far the least eutrophic and least polluted of the four lakes selected for comparison.

In both surface area and water chemistry Pigeon Lake (36 ha - 90 acres) is most similar to Stony Lake (113 ha - 278 acres). However, the uniqueness of a Lake Michigan inflow sets Pigeon Lake apart. Thermal and chemical stratification, expected to occur in the 8-m deep west basin of Pigeon Lake, is apparently disrupted by inflowing Lake Michigan water. Unlike the four lakes selected for comparison, dissolved oxygen concentrations varied little throughout the water column in Pigeon Lake; 5.8-6.0 mg of oxygen/L in the central basin and 9.0-10.0 mg of oxygen/L in the west basin. Likewise, ammonia was uniformly distributed from surface to bottom in Pigeon Lake, never exceeding 0.065 mg NH^3/L. In contrast, the hypolimnetic waters of Lakes Macatawa, Mona, Muskegon, and Stony approached anoxia (<4.0 mg oxygen/L) at most sampling stations and were found to be high in ammonia, generally greater than 0.2000 mg NH^3/L and occasionally exceeding 2.000 mg NH^3/L (Mona Lake). Total phosphorus levels in the central basin of Pigeon Lake (0.207-0.251 mg total P/L) were most similar to levels in Muskegon Lake; whereas, substantially lower levels of total phosphorus were found in the west basin (0.056-0.073 mg total P/L). Dilution of the enriched riverine waters of the central basin presumably by inflowing Lake Michigan water is evidenced by intermediate levels of total phosphorus in the intake canal (0.077-0.103 mg total P/L). Thus, basin morphology and hydrology have led to the isolation of two physically, chemically, and biologically distinct water masses within Pigeon Lake (i.e., the west and central basins).

As a relatively small body of water, Pigeon Lake would have a limited capacity to buffer the effects of nutrient loading. Unlike the more eutrophic lakes such as Macatawa, Mona, and Muskegon, Pigeon Lake is not a receiving basin for municipal sewage treatment effluent. However, Pigeon River does receive effluent from a poultry processing plant (Water Resources Commission 1968) and ash settling ponds operated by Consumers Power Company. In view of the extensive amount of agricultural development within the Pigeon River drainage area, most nutrient loading of Pigeon Lake probably results from land runoff.

ALGAE

A vast array of periphytic species of algae (Table 25) was found during a cursory examination of a heavily clogged seine haul sample collected during July 1979 at station V (undisturbed Pigeon Lake). Besides a great quantity of blue-green and green filamentous algae, many species of diatoms, including 10

Table 24. Physical and chemical parameters measured in the east and west basins of Stony Lake, Oceana County, Michigan, June 1975. (From Storet Retrieval System).

Station	Date	Depth (m)	Water Temperature (C)	Secchi Disc (m)	Dissolved Oxygen (mg/L)	pH	Total Alkalinity as $CaCO_3$ (mg/L)	Hardness as $CaCO_3$ (mg/L)	Nitrate NO_2&NO_3-N (mg/L)	Ammonia NH_3-N (mg/L)	Total Phosphorous (mg/L)	Ortho-phosphate (mg/L)	Chloride (mg/L)
01	26 Jun	surface 0.00	24.0	1.98	4.9	8.40	154	170	0.760	0.020	0.020	0.010	7.6
		mid-depth 3.05	23.0		5.0	8.40	153	168	0.760	0.020	0.020	0.010	7.5
		bottom 12.19	8.0		0.3	7.30	170	181	0.400	0.680	0.060	0.020	7.7
02	28 Jun	surface 0.00	23.5	0.61	4.2	8.20	145	164	0.770	0.030	0.040	0.020	7.2
		mid-depth 4.52	16.1		4.2	7.90	158	170	0.890	0.040	0.030	0.010	7.5
		bottom 7.62	10.0		2.4	7.50	162	180	0.890	0.110	0.020	0.010	7.7
Mean values for stations 01 and 02 combined	Jun	surface							0.765	0.025	0.030	0.015	
		mid-depth							0.825	0.030	0.025	0.010	
		bottom							0.645	0.395	0.040	0.015	

Table 25. A partial list of periphytic algal species found in a sample of algae and vegetation collected during a seine haul at station V (undisturbed Pigeon Lake) July 1979. Species identified by Janice Pappas, Great Lakes Research Division.

SPECIES	SPECIES
Achnanthes minutissima *	*M. varians*
A. lanceolata	*M. distans v. alpigena*
A. lanceolata v. dubia	*Meridion circulare*
Amphora perpusilla	*Navicula latens*
Asterionella formosa	*N. menisculus v. upsaliensis*
Cyclotella temperei	*N. gregaria*
C. stelligera	*N. capitata*
C. operculata	*N. capitata v. luneburgensis*
C. ocellata	*N. vulpina*
C. meneghiniana	*N. cryptocephala v. intermedia*
Diatoma tenue	*N. micropupula*
D. tenue v. elongatum	*Nitzschia palea*
Cymbella prostrata	*N. acicularis*
C. minuta	*N. dissipata*
Cymatopleura solea	*N. recta*
Cocconeis placentula v. euglypta	*N. acicularioides*
Diploneis oculata	*Monochrysis aphanaster*
Fragilaria capucina	*Pediastrum duplex*
F. capucina v. mesolepta	*Rhoicosphenia curvata*
F. construens	*Rhizosolenia gracilis*
F. construens v. capitata	*R. eriensis*
F. crotonensis	*Scenedesmus spinosus*
F. pinnata	*S. acuminatus*
F. pinnata v. lancettula	*S. quadricauda*
F. intermedia	*S. bicellularis*
F. vaucheriae	*Stephanodiscus tenuis*
F. vaucheriae v. truncata	*Synedra ostenfeldii*
F. brevistriata v. inflata	*S. delicatissima v. angustissima*
Gloeocystis planctonica	*S. filiformis*
Gomphonema constrictum	*S. ulna*
G. olivaceum	*S. pulchella*
Melosira granulata	*Tabellaria fenestrata v. intermedia*

* For pictures and descriptions, see: Patrick & Reimer, "The diatoms of the United States", vol. 1; Hustedt, various papers on the genus Nitzschia; Prescott, "Algae of the western Great Lakes area".

Fragilaria species and 8 Navicula species, were present in this sample. Again because of the great diversity of habitats and water conditions in Pigeon Lake, we would expect a great diversity of aquatic plants and animals.

Michigan State University (Consumers Power Company 1975) studied the phytoplankton of Pigeon Lake in 1972 and found a large number of diatoms in the lake on 14 August 1972. Some filamentous algae and green algae were also observed.

AQUATIC MACROPHYTES

The highly diverse aquatic habitat of Pigeon Lake supports an abundant and diverse growth of aquatic plants. Michigan State University (Consumers Power Company 1975) found in excess of 60 species, distributed in 46 genera and 32 families, in Pigeon Lake. These plants included submergent, emergent, floating, and semi-aquatic species. Our species list and that of Michigan State University are presented in Table 26. As during the 1975 study, absence of flowering or fruiting parts precluded identification to species of some plants.

The eastern portion of Pigeon Lake (east of Lakeshore Drive) is densely vegetated. The dominant forms of emergent vegetation in the shallow areas of this portion of the lake were Scirpus and Sparganium, with varieties of Typha, Pontederia, and Juncus common. Nuphar and Nymphaea were also abundant in the eastern portion of the lake. Submergent vegetation was present in all but the narrow river channel section of this portion of Pigeon Lake. Myriophyllum, Ceratophyllum, Elodea, and Potamogeton (primarily P. crispus) were the principal submergents in this portion of the lake. As during the 1975 survey, Vallisneria and Chara were found in scattered disjunct portions of the eastern section of Pigeon Lake. Lemna minor was abundant during early spring and summer months, with Lemna trisulca and Spirodela polyrhiza also common.

The major portion of Pigeon Lake lies west of Lakeshore Drive. Throughout most spring and summer months, areas in Pigeon Lake at depths of approximately 1 m were choked with submergent vegetation, the dominant types being Myriophyllum, Ceratophyllum, and Potamogeton (Fig. 12). The eastern and northern shorelines have gradual slopes which accomodate abundant growth of emergent vegetation, with the dominant being Scirpus; Sparganium and Typha were common (Fig. 13). The southern shoreline of Pigeon Lake has a steep gradient showing little emergent vegetation with the exception of a few isolated patches of Scirpus. It is likely that maintenance of numerous docking facilities on the southern shoreline prevents establishment of extensive emergent and submergent vegetation. Submergent vegetation was restricted to scattered patches of Myriophyllum or Potamogeton. In the area immediate to the small island in the southeastern portion of Pigeon Lake, emergent and submergent plants similar to those observed along the northern shoreline were found. This small island appears to receive at least minimal maintenance by landowners to enhance the area as a roost for songbirds and wild and domestic ducks.

The western shore of Pigeon Lake has been altered considerably from its natural condition by activities of a dock and dredge company. A steep shoreline was dredged which changed the vegetation. Emergent vegetation (mainly Scirpus and Typha) exists on the extreme fringes. In those western shoreline areas where dredging was not complete, and also along the northern

Table 26. Relative abundances of aquatic macrophytes in Pigeon Lake, Ottawa County, Michigan.

Plant species	Relative abundance in present study (1980)	Relative abundance in 1972 (Consumers Power Company 1975)
Division CHLOROPHYTA		
CHARACEAE		
Chara sp.	abundant	abundant
Division PTERIDOPHYTA		
EQUISETACEAE		
Equisetum sp.	abundant	abundant
E. arvense L.	*	abundant
E. hyemale L.	*	common
TYPHACEA		
Typha angustifolia L.	common	common
Typha latifolia L.	common	common
SPARGANIACEAE		
Sparganium eurycarpum Engelm.	common	common
Sparganium sp.	not found	rare
POTOMOGETONACEAE		
Potamogeton spp. (approx. 4 sp.)	1 rare not found	common (3), rare (1)
Potamogeton crispus L.	common	
P. zosteriformis Fernald.	common	
P. praelongus Wulf.	common	
ALISMATACEAE		
Sagittaria sp.	common	common
HYDROCHARITACEAE		
Elodea canadensis Michx.	abundant	abundant
Vallisneria americana Michx.	common	common
CYPERACEAE		
Carex hystricina Muhl.	*	common
C. straminea Willd.	*	common
C. spp. (2 sp.)	common	rare
Cladium mariscoides Torr.	not found	rare
Cyperus sp.	common	common
Eleocharis spp. (2 sp.)	common	common
Scirpus expansus (Fern.)	*	abundant
S. spp. (approx. 2 sp.)	abundant	common
ARACEAE		
Peltandra virginica (L.) Kunth.	common	common

Table 26. Continued.

Plant species	Relative abundance in present study (1980)	Relative abundance in 1972 (Consumers Power Company 1975)
LEMNACEAE		
Lemna minor L.	abundant	common
L. trisulca L.	common	common
Spirodela polyrhiza (L.) Schleiden	abundant	abundant
PONTEDERACEAE		
Pontederia cordata L.	common	common
JUNCACEAE		
Juncus balticus Willd. var *littoralis* Englem.	*	common
Juncus effusus L.	*	common
Juncus spp.	common	
POLYGONACEAE		
Polygonum spp.	common	common
Rumex spp.	common	common
CERATOPHYLLACEAE		
Ceratophyllum demersum L.	abundant	common
NYMPHACEAE		
Nuphar variegatum Engelm.	common	common
Nymphaea odorata Ait.	common	common
HALORACIDACEAE		
Myriophyllum spp.	abundant	abundant
LENTIBULARIACEAE		
Utricularia vulgaris L.	not found	rare
CAMPANULACEAE		
Campanula sp.	not found	rare
COMPOSITAE		
Bidens sp.	not found	rare

*denotes species identification not possible. Abundance noted at generic level.

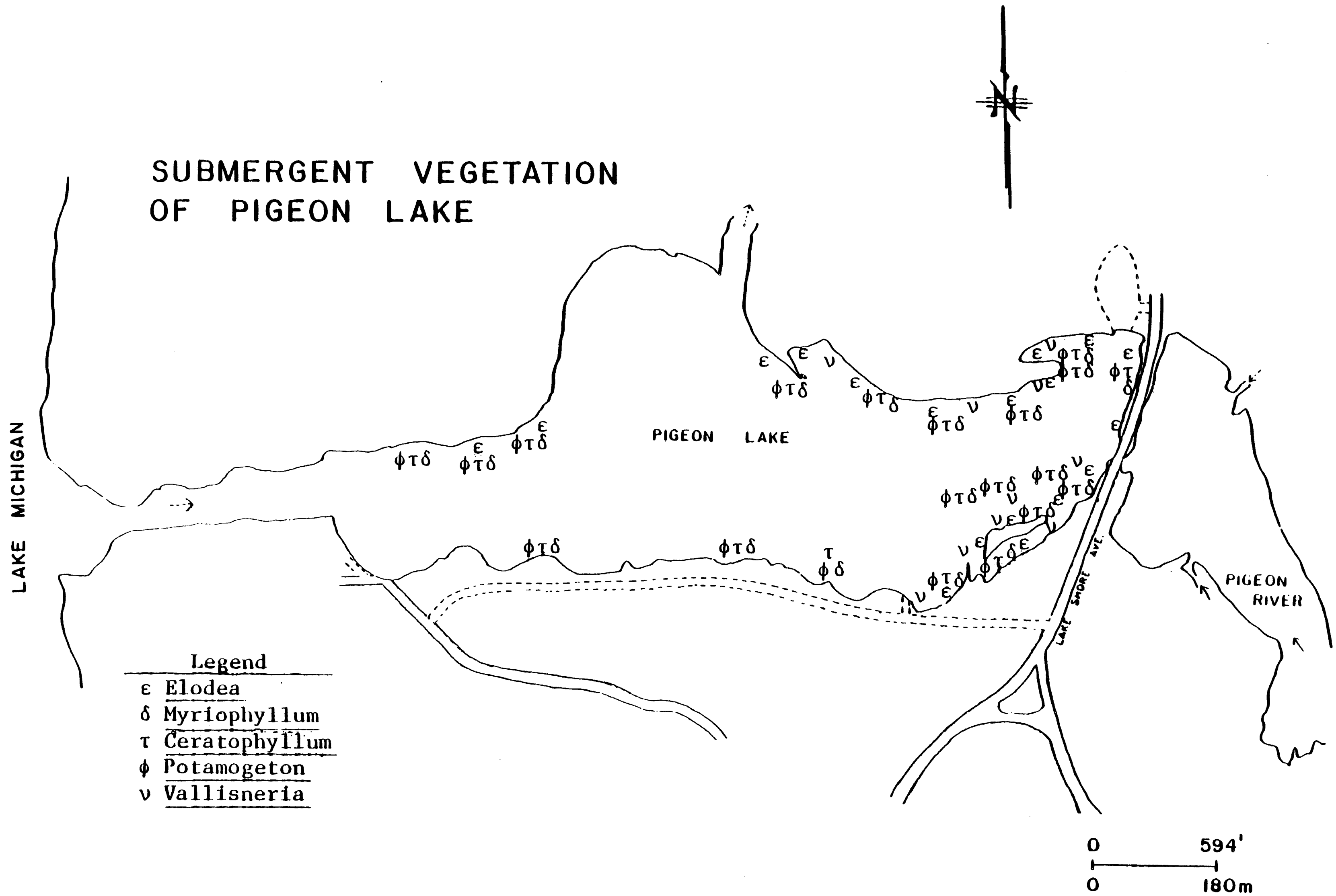

Fig. 12. Distribution of submergent vegetation in Pigeon Lake during June and August 1980. Scientific names were assigned according to Fassett (1972).

shore of the inlet channel to Lake Michigan, large patches of submergent vegetation (primarily P. crispus and Myriophyllum) were recorded.

In general, Pigeon Lake has dense vegetation in over one half of its area (Figs. 12, 13 and 14). Although this vegetation was considered by most boat operators and fishermen as a nuisance, electroshocking operations indicated a strong correlation between vegetated areas and fish abundance. Areas of Nuphar and Nymphaea with Scirpus on the margin typically have higher occurrences of northern pike, bowfin, and largemouth bass. Minnow populations as well as fry of centrarchids and perch were commonly associated with dense beds of P. crispus and Ceratophylum when this plant growth did not reach the surface, thus allowing areas of quick retreat and cover from predatory fish. It is unknown whether the vegetative cover in Pigeon Lake causes a stunting of the centrarchid and perch population by providing excessive cover and thus causing overpopulation.

ZOOPLANKTON

Copepoda

In their 1972 study of Pigeon Lake Tack et al. (Consumers Power Company 1975) observed cyclopoid copepods to be more common than calanoid copepods. This again was the case in 1980 when we found very few calanoid copepods; more were observed at beach station S (influenced by Lake Michigan) than in the undisturbed water near the bridge. A few adult Diaptomus ashlandi were encountered at station S during the day, and several adult Eurytemora affinis were observed in samples taken at night at this station. Station S samples also contained several adult male Cyclops vernalis and a few Mesocyclops edax. Copepod nauplii and immature copepods comprised the most significant percentage of organisms encountered (Table 27), and were more abundant in the area influenced by Lake Michigan.

The cyclopoid copepods, Cyclops bicuspidatus thomasi and C. vernalis, were observed attached to larval fish collected from Pigeon Lake in 1978 and 1979. These copepods were found on 16 larvae (2 rainbow smelt and 14 yellow perch) recovered from five samples during May 1978. Predation occurred on 10.7% of the total 150 larvae collected. All attachments were found in night samples.

In 1979 attached copepods were most frequently observed at open water station M (influenced by Lake Michigan) and beach stations X and V (undisturbed Pigeon Lake). Of 1384 larvae collected in seven Pigeon Lake samples, 262 or 18.9% were found to have at least 1 copepod attached; 245 or 17.7% of these larvae were yellow perch. Again, all but three of these occurrences were detected in night samples.

Cyclopoid copepods exhibit vertical migration, often rising from the bottom at night. Yellow perch larvae, particularly abundant during May 1979, became easy prey. Copepods were attached to yellow perch 5.0 to 11.0 mm TL, but most frequently to those 5.5 to 7.5 mm TL. This size range is typical of newly hatched yellow perch which apparently are highly susceptible to predation due to their abundance and erratic movements. Copepods have also been observed attached to larval Pomoxis spp., burbot, and smelt during May. The frequency of attached copepods decreased throughout the remainder of the year in both 1978 and 1979.

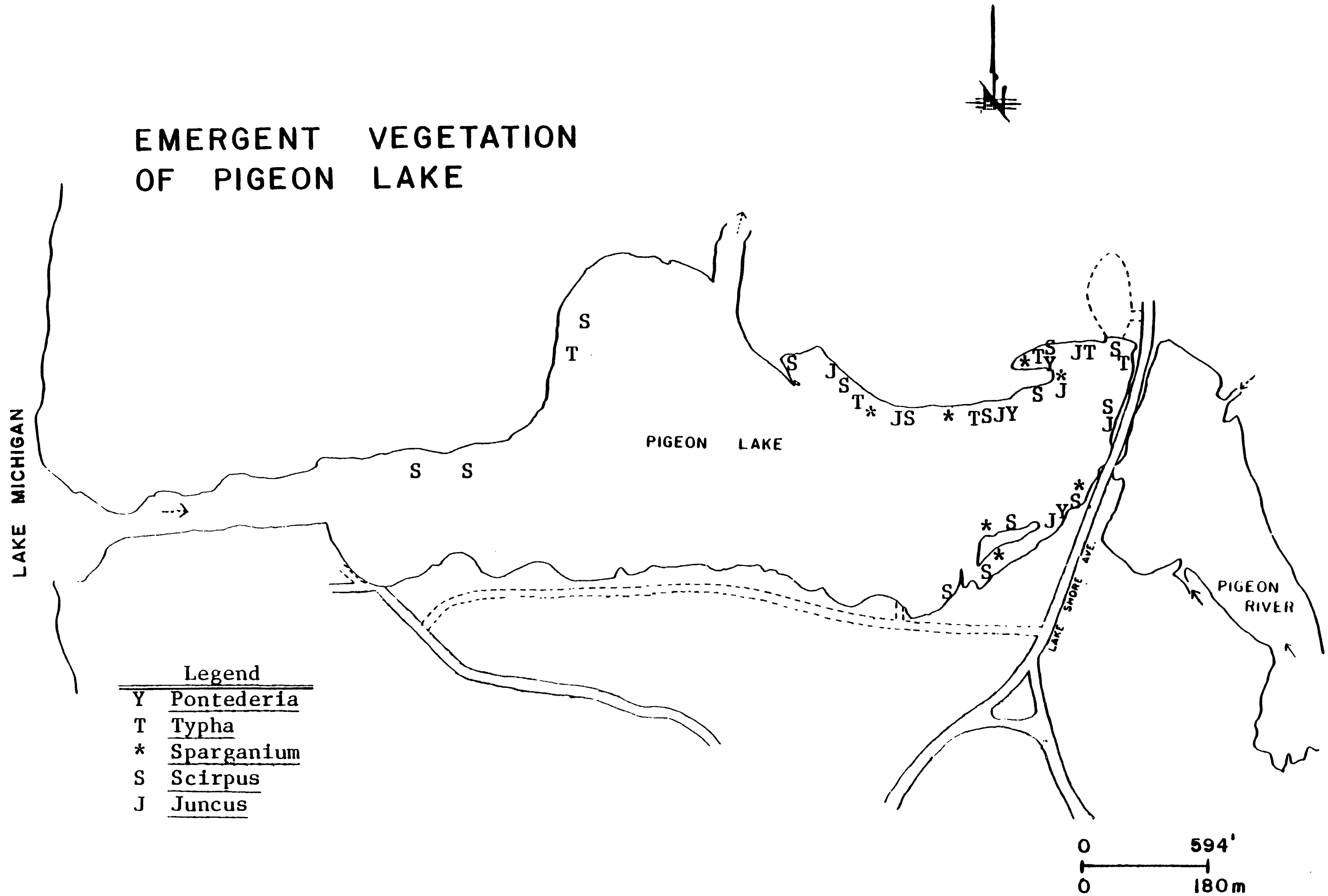

Fig. 13. Distribution of emergent vegetation in Pigeon Lake during June and August 1980. Scientific names were assigned according to Fassett (1972).

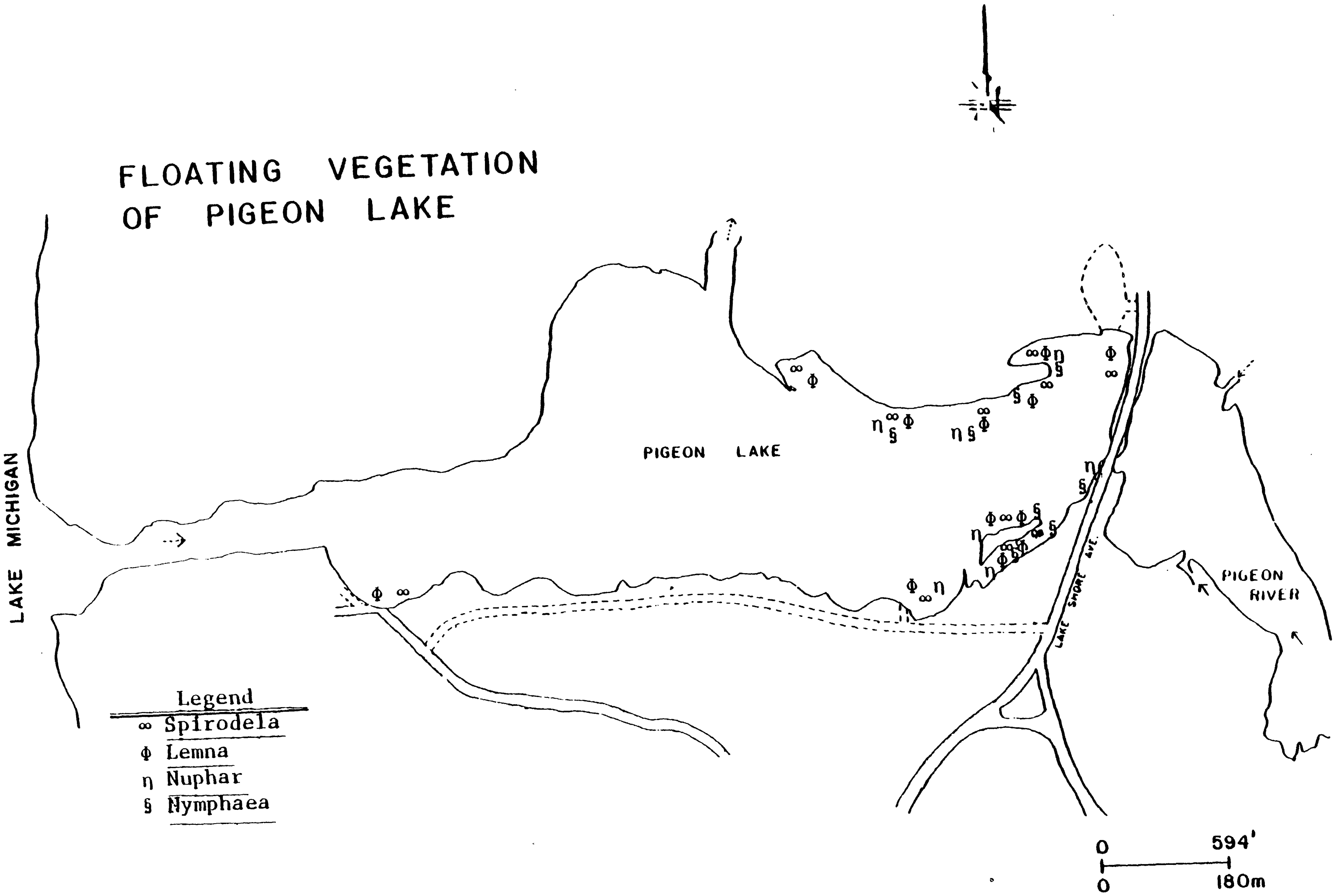

Fig. 14. Distribution of floating vegetation in Pigeon Lake during June and August 1980. Scientific names were assigned according to Fassett (1972).

Table 27. Percent composition of zooplankton collected from Pigeon Lake, June 1980.

Species	UNDISTURBED PIGEON LAKE Bridge Station		INFLUENCED BY LAKE MICH. Station S	
	Day	Night	Day	Night
Nauplii	0.31	0.30	6.18	1.95
Immature *Cyclops* spp.	3.24	3.44	14.96	14.81
C. vernalis (male)		0.15	2.60	8.77
C. vernalis (female)	0.15		0.65	1.36
C. bicuspidatus (male)		0.15		
Mesocyclops edax				0.58
Immature *Diaptomus* spp.	0.15	0.45	3.90	0.78
D. ashlandi (male)			0.33	
D. ashlandi (female)			0.65	
Immature *Eurytemora* spp.	0.15	0.30	0.49	
E. affinis (male)				0.78
E. affinis (female)				0.19
Bosmina spp.	94.29	91.78	53.50	63.74
Chydorus spp.	1.70	2.24	8.29	4.68
Daphnia spp.		0.30	0.16	0.58
Ceriodaphnia spp.		0.30	0.33	
Eurycercus spp.		0.15		0.19
Asplanchna spp.		0.15	7.97	1.56

In July-August 1978, 5 alewife larvae had attached copepods in four Pigeon Lake samples, while in 1979, 19 alewives and 1 yellow perch showing predation were taken from four Pigeon Lake June and July samples. In another study at the D.C. Cook Plant, southeastern Lake Michigan (Hartig, Jude, and Evans; unpublished manuscript), similar copepod predation by *C. bicuspidatus thomasi* and *C. vernalis* was documented. Only small, slow-swimming larvae were attacked; almost 98% of the attacks occurred at night in July, when both newly hatched larvae and the copepods attained spatial and temporal proximity.

Cladocera

Cladocerans were the most numerous zooplankters observed. *Bosmina* spp. and *Chydorus* spp. were extremely abundant. *Daphnia* spp., *Ceriodaphnia* spp., and *Eurycerus* spp. were rare in samples examined. Tack et al. (Consumers Power Company 1975) found *Bosmina* spp. to be the most dominant organism. In our study *Bosmina* spp. comprised 90 to 95% of the organisms observed near the bridge and 50 to 65% of the organisms in beach station S samples.

Rotifera

Three genera of Rotifera were commonly observed in Pigeon Lake samples; those of *Keratella* and *Kellicottia* which were not enumerated and those of *Asplanchna* which were. *Asplanchna* was much more abundant at the Lake Michigan-influenced station (S) than at the undisturbed station near the bridge.

Summary

Data indicate that the zooplankton population in the region of Pigeon Lake which is undisturbed by water from Lake Michigan is less diverse than that observed in areas where Lake Michigan water mixes with that from Pigeon Lake. Those organisms observed at station S commonly occur in the open water of Lake Michigan except for *C. vernalis*. Our results are similar to those reported by Tack et al. (Consumers Power Company 1975).

BENTHOS

A survey of Pigeon Lake conducted during June 1977 had as its primary objective determination of forms and densities of benthic macroinvertebrates occurring in the lake. During the course of the survey, six generalized habitat types were encountered: sandy, wave-washed shoreline, littoral, sublittoral, deep water (profundal), current-washed lake bottom, and peat bottom (see Fig. 3). The littoral, profundal and peat bottom habitats comprised the majority of the lake bottom area.

Eggleton (1936, 1937) characterized the littoral zone as extending from the shoreline to the deepest extent of aquatic vegetation. Consequently, the extent of the littoral zone could be different for each lake considered. For Pigeon Lake, the littoral zone was the area from shore to approximately 4 m and varied in area covered from relatively little in the western end of the western basin, southern shoreline, and the central portion of the eastern basin to fairly extensive along the northern shoreline of the eastern half of the western basin and that portion of the eastern basin surrounding the central area. While the shoreline habitat characterized as sandy and wave-washed could be included as part of the littoral zone, it has been maintained as a separate habitat type distinct from the littoral zone proper.

The deep-water or profundal portion of Pigeon Lake has been defined as that area of the lake greater than 6 m where gelatinous silt deposits predominated. Deep-water habitat occurred primarily in the central portion of the western half of the western basin.

Situated between the littoral and profundal zones at approximately 4-6 m is the sublittoral zone which corresponds to that portion of the lake from the deepest extent of rooted aquatic macrophytes to the regular occurrence of gelatinous silt deposits. Because sediment type present in the sublittoral zone was variable, it was divided into silty sand and sandy silt habitat types.

The offshore area of the eastern basin of Pigeon Lake was comprised primarily of peat; that is, a thick layer of organic detritus, underlying approximately 1 m of water. Although some macrophytic growth was evident, extensive organic detrital material was the most striking characteristic. While the nearshore area had a bottom type similar to the offshore area of the eastern basin, presence of luxuriant amounts of macrophytic growth distinguished it from the offshore area of the eastern basin.

The final habitat type was the most limited habitat type in Pigeon Lake. Designated as clean sand, this type was generally free of large quantities of silt and organic detritus which were present in all other habitat types. Location of the clean sand habitat was near the culvert that allowed water to pass under Lakeshore Drive from the eastern to the western basin of Pigeon Lake. Water currents were generated by the narrow water passage with subsequent scouring of sediments in the immediate vicinity of the culvert.

Based on samples collected with a ponar grab sampler during June 1977, there were 150 identifiable benthic taxa collected in Pigeon Lake (Table 28). Chironomidae, the non-biting midges, was the most diverse major taxonomic group with 56 identifiably different forms present. Other major taxonomic groups having numerous genera/species were: the caddisfly-Trichoptera (24), the oligochaetes-Naididae (20) and Tubificidae (16), and the snails-Gastropoda (7). Of these major taxonomic groups, Tubificidae was the most numerous group comprising 58% of the lake-wide mean density for total animals (32,674 m^{-2}, Table 29). Other than tubificids, only chironomids (19%) and malacostracans (13%), i.e., Amphipoda and Isopoda, comprised significant proportions of all animals collected. All remaining major taxonomic groups comprised approximately 10% of the total benthic mean density in the lake.

Percent composition of major taxonomic groups varied among habitat types. Chironomids and malacostracans dominated in the shoreline, littoral, and peat habitat types, while tubificids were most abundant in sublittoral and deep water habitats. The observed distribution of the three major taxonomic groups conformed to the pattern observed in other small eutrophic lakes. General absence of ephemeropterans, hemipterans, odonates, coleopterans, and other swift moving insects was likely due to sampling device inefficiency. Percent composition of major taxonomic groups may have been altered somewhat had another more efficient sampler been used to collect more insects capable of quick evasion. In addition, presence of oligochaetes in the littoral zone may have been underestimated due to dense growths of macrophytes fouling the ponar and inhibiting an unobstructed bite into sediments where tubificids, in particular, would be expected to occur in abundance.

Table 28. Benthic macroinvertebrates identified from samples collected during 1977 in Pigeon Lake, near Port Sheldon, Michigan.

TAXA	TAXA
Annelida	Hirudinea
Oligochaeta	Glossiphoniidae
Tubificidae	*Helobdella stagnalis*
Aulodrilus pluriseta	*Glossiphonia complanata*
Aulodrilus pigueti	
Aulodrilus limnobius	Malacostraca
Limnodrilus hoffmeisteri	Amphipoda
Limnodrilus cervix	Gammaridae
Limnodrilus claparedeianus	*Gammarus* sp.
Limnodrilus profundicola	Talitridae
Limnodrilus udekemianus	*Hyalella azteca*
Peloscolex freyi	Isopoda
Peloscolex multisetosus multisetosus	Asellidae
Peloscolex multisetosus longidentis	*Asellus* sp.
Tubifex tubifex	*Lirceus* sp.
Ilyodrilus templetoni	
Potamothrix vejdovskyi	Mollusca
Potamothrix moldaviensis	Pelecypoda
Potamothrix bedoti	Sphaeriidae
Lumbriculidae	*Pisidium* sp.
Stylodrilus heringianus	*Sphaerium* sp.
Lumbriculid	Gastropoda
Enchytraeidae	Hydrobiidae
Naididae	*Amnicola* sp.
Nais variabilis	*Bithynia tentaculata*
Nais bretscheri	Valvatidae
Nais simplex	*Valvata tricarrinata*
Nais elinguis	Physidae
Nais communis	*Physa* sp.
Nais sp.	Viviparidae
Ophidonais serpentina	*Campeloma* sp.
Dero digitata	Ancylidae
Dero sp.	*Ferrisia* sp.
Arcteonais lomondi	Planorbidae
Vejdovskyella intermedia	*Menetus* sp.
Vejdovskyella comata	
Pristina foreli	Turbellaria
Uncinais uncinata	
Piguetiella michiganensis	Hydracarina
Amphichaeta leydigii	
Stylaria lacustris	Coelenterata
Stylaria fossularis	Hydrozoa
Chaetogaster diaphanus	Hydridae
Haemonais waldvogeli	*Hydra* sp.

Table 28. Continued.

TAXA	TAXA
Insecta	Phryganeidae
Lepidoptera	*Phryganea* sp.
Coleoptera	Limnephilidae
Haliplidae	*Limnephilus* sp.
Peltodytes sp.	Polycentropodidae
Gyrinidae	*Polycentropus* sp.
Dineutus sp.	Unknown
Gyrinus sp.	Unknown trichopteran
Chrysomelidae	Diptera
Galerucella sp.	Chironomidae
Curculionidae	*Chironomus* sp.
Dytiscidae	*Chironomus plumosus*-gr.
Hemiptera	*Chironomus semi-reductus*-gr.
Notonectidae	*Chironomus anthracinus*-gr.
Notonecta sp.	*Cryptochironomus* cfr. *fulvus*
Pleidae	*Cryptochironomus* cfr. *digitatus*
Plea striola	*Cryptochironomus* sp.
Ephemeroptera	*Polypedilum* cfr. *scalaenum*
Caenidae	*Polypedilum* cfr. *halterale*
Caenis sp.	*Polypedilum* cfr. *ophioides*
Unknown	*Polypedilum* cfr. *flavus*
Odonata	*Paratendipes* sp.
Coenagrionidae	*Microtendipes* sp.
Enallagma sp.	*Dicrotendipes* sp.
Trichoptera	*Glyptotendipes* sp.
Hydroptilidae	*Endochironomus* sp.
Agralea multipunctata	*Cladopelma* sp.
Agralea sp.	*Phaenopsectra* sp.
Oxyethira sp.	*Paracladopelma* cfr. *nereis*
Unknown	*Paracladopelma* cfr. *undine*
Leptoceridae	*Parachironomus* cfr. *abortivus*
Ceraclea inconspicua	*Parachironomus* sp. 2
Ceraclea transvera	*Parachironomus* sp. 3
Ceraclea alagma	*Parachironomus* sp. 4
Ceraclea sp.	*Saetheria* cfr. *tylus*
Oecetis cenerascens	*Robackia* cfr. *demeijerei*
Oecetis inconspicua	n. *Goeldochironomus*
Oecetis sp. A	*Psectrocladius* sp. 1
Oecetis sp. B	*Psectrocladius* sp. 2
Oecetis sp.	*Thienemanniella* sp.
Leptocerus americanus	*Corynoneura* sp.
Leptocerus sp.	*Cricotopus* spp.
Leptocerid sp. A	*Nanocladius* sp.
Setodes sp.	
Triaenodes sp.	
Nectopsyche sp.	

Table 28. Continued.

TAXA
Pseudosmittia cfr. *gracilis*
Pseudosmittia sp.
Orthocladiini sp. 1
Orthocladiini sp. 2
Orthocladiini sp. 3
Orthocladiini sp. 4
Orthocladiini sp. 5
Monodiamesa cfr. *depectinata*
Tanytarsus sp.
Cladotanytarsus sp.
Paratanytarsus sp.
Rheotanytarsus sp.
Micropsectra sp.
Procladius sp. 1
Procladius sp. 2
Procladius sp. 3
Clinotanypus sp.
n. *Guttipelopia*
Thienemannimyia-gr.
Ablabesmyia sp.
Tanypodini sp. 1
Tanypodini sp. 2
Tanypodini sp. 3
Ceratopogonidae
Ephydridae

Table 29. Mean density and percentage (expressed in terms of mean number of total animals collected in each habitat type) of major taxonomic groups occurring in each habitat type encountered in Pigeon Lake during June 1977. Number in parenthesis is the number of samples used to generate mean densities for each taxon in each habitat type.

	Habitat Type															
	Shoreline		Littoral		*Sublittoral		#Sublittoral		Deep Water		Peat Bottom		Clean Sand		Lake Wide	
Taxon	Mean (3)	%	Mean (21)	%	Mean (2)	%	Mean (1)	%	Mean (3)	%	Mean (6)	%	Mean (3)	%	Mean (39)	%
Chironomidae	3350	31.9	9431	32.3	2304	11.2	4467	2.8	3297	2.5	1522	30.5	864	44.2	6117	18.7
Tubificidae	179	1.4	8323	28.5	15623	75.7	153777	94.9	126127	96.9	406	8.1	146	7.5	19015	58.2
Naididae	292	2.8	870	3.0	1316	6.4	2552	1.6	638	0.5	286	5.7	492	25.2	755	2.3
Hirudinea	618	5.9	745	2.7	0	0	0	0	0	0	426	8.5	53	2.7	518	1.6
Malacostracan	4899	46.7	7057	24.2	419	2.5	0	0	0	0	1675	33.6	119	6.1	4470	13.7
Gastropoda	319	3.0	1292	4.4	240	1.2	0	0	0	0	306	6.1	27	1.4	782	2.4
Sphaeriidae	20	0.2	41	0.1	479	2.3	0	0	0	0	4	0.1	173	8.9	62	0.2
Hydracarina	106	1.0	323	1.1	120	0.6	638	0.4	106	0.1	124	2.5	20	1.0	233	0.7
Turbellaria	13	0.1	192	0.7	50	0.2	638	0.4	0	0	4	0.1	0	0	124	0.4
Total Animals	10502	-	29197	-	20628	-	162072	-	130168	-	4992	-	1954	-	32674	-

*Silty sand sediments.

#Sandy silt sediments.

Considering habitat types sampled, the current-swept, clean-sand habitat near the culvert separating the two basins of Pigeon Lake and the silty sandy sublittoral habitat most closely resembled nearshore habitats of Lake Michigan. Animals found were similar to the benthic community structure in the 3-6-m depths of Lake Michigan where physical forces (e.g., wind, current) exert major control over nearshore processes. In the clean-sand habitat of Pigeon Lake, chironomids (44%) and naidids (25%) comprised the greatest proportion of the benthos (Table 29). Four chironomid species were found in Pigeon Lake which also occurred commonly in nearshore Lake Michigan. *Robackia* cf. *demeijerei* and *Polypedilum* cf. *scalaenum* were the most numerous chironomids found in Pigeon Lake clean-sand habitat, while *Paracladepelma* cf. *undine* and *Paracladopelma* cf. *nereis* were found only in the clean sand.

R. cf. *demeijerei*, *P.* cf. *scalaenum* and *Saetheria* cf. *tylus*, another chironomid characteristic of nearshore Lake Michigan, were collected in the silty sandy sublittoral habitat. Although *R.* cf. *demeijerei* and *S.* cf. *tylus* were represented by only a single individual each, *P.* cf. *scalaenum* was represented by numerous specimens. Decreasing densities of *R.* cf. *demeijerei* and *S.* cf. *tylus* and increasing density of *P.* cf. *scalaenum* as depth increased corresponded to expected chironomid distributions observed at approximately 9-12 m in Lake Michigan. Although both clean-sand and silty sandy sublittoral habitat types had chironomid taxa characteristic of the nearshore Lake Michigan chironomid fauna, other chironomid taxa were also present that were not found in Lake Michigan in the vicinity of the J.H. Campbell Plant. Therefore, while Pigeon Lake did appear to have some habitats capable of supporting chironomids characteristic of Lake Michigan, the majority of available area apparently did not support similar specific taxa where species were determinable. Given the nature of the lake's morphology, sediments, macrophytic growth, and types of benthic macroinvertebrates collected among habitat types encountered, it is apparent that Pigeon Lake is a small eutrophic lake.

FISH DISTRIBUTION AND ABUNDANCE

Total Catch

In examining general trends in abundance of adult and juvenile fish in Pigeon Lake for the 3 yr of the study, note that our fishing effort per month decreased from 1977 to 1978 and again from 1978 to 1979 (see METHODS). Briefly, the 1977 sampling involved June through November for seining (three stations) and June through December for bottom gillnetting (two stations). In 1978 bottom gill nets were set at one station from April through December and seining was conducted from April through November at two stations. In 1979 gillnetting was dropped after April, while seining continued at two stations. Data presented on adult and juvenile fish were taken from Jude et al. (1978, 1979a, 1980). The annual total catch and number of species in Pigeon Lake fluctuated considerably from 1977 to 1979 (Tables 30, 31). Total catch dropped from over 20,000 fish in 1977 to just over 10,000 in 1978, but in 1979 total catch increased to 18,750 (Table 31). Reasons for the relatively low catch in 1978 are not clear. Most fish caught in Pigeon Lake were YOY; perhaps the conditions in Pigeon Lake were such that survival of YOY was relatively poor for some major species (particularly alewife) during 1978. Docking of barges and construction activity in Pigeon Lake began in 1978 and this may have affected the catch of fish. Our sampling may have missed the peak concentrations of some major species during that year.

Table 30. Scientific name, common name and abbreviations for all species of fish captured from the Campbell Plant study areas in 1977, 1978 and 1979 (Jude et al. 1978, 1979, 1980); Lake Macatawa in May 1966, March 1969, September 1971 and October 1978; Muskegon Lake in April 1978 and July 1975 and Mona Lake in May 1977 and April 1978 (from MDNR Fish Division - Lake Fish Collection files). An X denotes presence in either Lake Michigan, Pigeon Lake, Lake Macatawa, Muskegon Lake or Mona Lake. Fish collection data were not available for Stony Lake. Names were assigned according to Bailey et al. 1970.

Scientific and Common Name	Abbreviation	Lake Michigan	Pigeon Lake	Lake Macatawa	Muskegon Lake	Mona Lake
Amiidae						
Amia calva Linnaeus Bowfin	BF		X	X	X	
Aphredoderidae						
Aphredoderus sayanus (Gilliams) Pirate perch	PR		X			
Atherinidae						
Labidesthes sicculus (Cope) Brook silverside	SV	X	X			
Catostomidae						
Carpiodes cyprinus (Lesueur) Quillback	QL	X	X	X		
Erimyzon sucetta (Lacépède) Lake chubsucker	ER		X			
Catostomus catostomus (Forster) Longnose sucker	LS	X	X			
Catostomus commersoni (Lacépède) White sucker	WS	X	X	X	X	
Hypentelium nigricans (Lesueur) Northern hog sucker	HS*				X	
Moxostoma macrolepidotum (Lesueur) Shorthead redhorse	SR	X	X			
Moxostoma erythrurum (Rafinesque) Golden redhorse	GR	X	X			
Centrarchidae						
Ambloplites rupestris (Rafinesque) Rock bass	RB		X		X	
Lepomis cyanellus Rafinesque Green sunfish	GN*	X	X			
Lepomis gibbosus (Linnaeus) Pumpkinseed	PS	X	X	X	X	X

Table 30. Continued.

Scientific and Common Name	Abbreviation	Lake Michigan	Pigeon Lake	Lake Macatawa	Muskegon Lake	Mona Lake
Lepomis gulosus (Cuvier) Warmouth	WM		X			
Lepomis macrochirus Rafinesque Bluegill	BG	X	X	X	X	X
Micropterus dolomieui Lacépède Smallmouth bass	SB	X	X	X		
Micropterus salmoides (Lacépède) Largemouth bass	LB		X	X	X	X
Pomoxis nigromaculatus (Lesueur) Black crappie	BC		X	X	X	X
Pomoxis annularis Rafinesque White crappie	WC		X	X		
Clupeidae						
Alosa psuedoharengus (Wilson) Alewife	AL	X	X	X	X	
Dorosoma cepedianum (Lesueur) Gizzard shad	GS	X	X	X	X	
Cottidae						
Cottus bairdi Girard Mottled sculpin	MS	X	X			
Cottus cognatus Richardson Slimy sculpin	SS	X	X			
Cyprinidae						
Carassius auratus (Linnaeus) Goldfish	GF	X	X	X		
Cyprinus carpio Linnaeus Carp	CP	X	X	X	X	
Notomigonus crysoleucas (Mitchill) Golden shiner	GL		X	X		
Notropis atherinoides Rafinesque Emerald shiner	ES	X	X			
Notropis cornutus (Mitchill) Common shiner	CS		X			
Notropis dorsalis (Agassiz) Bigmouth shiner	BS		X			
Notropis heterolepis Eigenmann and Eigenmann Blacknose shiner	NH		X			
Notropis hudsonius (Clinton) Spottail shiner	SP	X	X		X	

Table 30. Continued.

Scientific and Common Name	Abbreviation	Lake Michigan	Pigeon Lake	Lake Macatawa	Muskegon Lake	Mona Lake
Notropis stramineus (Cope) Sand shiner	SH		X			
Pimephales notatus (Rafinesque) Bluntnose minnow	BM	X	X	X		
Pimephales promelas Rafinesque Fathead minnow	PP	X	X			
Rhinichthys cataractae (Valenciennes) Longnose dace	LD	X	X			
Semotilus atromaculatus (Mitchill) Creek chub	CR		X			
Cyprinodontidae						
Fundulus diaphanus (Lesueur) Banded killifish	BK		X			
Esocidae						
Esox americanus vermiculatus Lesueur Grass pickerel	GP		X			
Esox lucius Linnaeus Northern pike	NP	X	X	X	X	
Esox lucius x masquinongy Tiger muskellunge	TM		X#			
Gadidae						
Lota lota (Linnaeus) Burbot	BR	X	X			
Gasterosteidae						
Pungitius pungitius (Linnaeus) Ninespine stickleback	NS	X	X			
Ictaluridae						
Ictalurus melas (Rafinesque) Black bullhead	BB		X			
Ictalurus natalis (Lesueur) Yellow bullhead	YB		X			
Ictalurus nebulosus (Lesueur) Brown bullhead	BN		X	X	X	
Ictalurus punctatus (Rafinesque) Channel catfish	CC	X	X	X		
Noturus gyrinus (Mitchill) Tadpole madtom	MT		X			

Table 30. Continued.

Scientific and Common Name	Abbreviation	Lake Michigan	Pigeon Lake	Lake Macatawa	Muskegon Lake	Mona Lake
Pylodictis olivaris (Rafinesque) Flathead catfish	FC*					
Lepisosteidae						
Lepisosteus oculatus (Winchell) Spotted gar	SG*			X		
Lepisosteus osseus (Linnaeus) Longnose gar	LR*					
Osmeridae						
Osmerus mordax (Mitchell) Rainbow smelt	SM	X	X		X	
Percidae						
Stizostedion vitreum vitreum (Mitchell) Walleye	WL	X	X#			
Etheostoma nigrum Rafinesque Johnny darter	JD	X	X			
Etheostoma exile (Girard) Iowa darter	EE		X			
Perca flavescens (Mitchell) Yellow perch	YP	X	X	X	X	
Percina caprodes (Rafinesque) Logperch	LP		X			
Percina maculata (Girard) Blackside darter	BD		X			
Percopsidae						
Percopsis omiscomaycus (Walbaum) Trout-perch	TP	X	X		X	
Petromyzontidae						
Ichthyomyzon castaneus Girard Chestnut lamprey	CL*					
Petromyzon marinus Linnaeus Sea lamprey	SL*					
Salmonidae						
Coregonus artedii Lesueur Cisco or lake herring	LH		X			
Coregonus clupeaformis (Mitchill) Lake whitefish	LW	X	X**			

Table 30. Continued.

Scientific and Common Name	Abbreviation	Lake Michigan	Pigeon Lake	Lake Macatawa	Muskegon Lake	Mona Lake
Coregonus spp. Unidentified coregoninae	XC	X	X			
Oncorhynchus kisutch (Walbaum) Coho salmon	CM	X	X			
Oncorhynchus tshawytscha (Walbaum) Chinook salmon	CH	X	X	X		
Salmo gairdneri Richardson Rainbow trout	RT	X	X	X		
Salmo trutta Linnaeus Brown trout	BT	X	X			
Salvelinus namaycush (Walbaum) Lake trout	LT	X	X			
Sciaenidae						
Aplodinotus grunniens Rafinesque Freshwater drum	FD		X†			
Umbridae						
Umbra limi (Kirtland) Central mudminnow	MM		X			

* Found in impingement samples.
# Based on observations made while electroshocking.
**Collected as larvae only.
† Caught by hook and line.

Table 31. Summary of all adult and juvenile fish collected in Pigeon Lake during study years. In 1972 fish were collected by electroshocking and hand dipnets; visual observation was also performed (Consumers Power 1975). Sampling was performed June-December 1977, April-December 1978 and April-December 1979 by Jude et al. (1978, 1979, 1980) using seines and gill nets. P = present.

Species	1972	1977		1978		1979	
		total no.	% of total	total no.	% of total	total no.	% of total
Alewife	P	7094	34.319	605	6.041	5178	27.616
Spottail shiner	P	4547	21.997	2456	24.523	3194	17.035
Golden shiner	P	2615	12.651	2220	22.167	20	0.107
Yellow perch	P	2459	11.896	1771	17.683	8195	43.707
Bluntnose minnow	-	1560	7.547	864	8.627	423	2.256
Largemouth bass	P	760	3.677	532	5.312	60	0.320
Pumpkinseed	P	232	1.122	114	1.138	23	0.123
Black crappie	P	183	0.885	246	2.456	49	0.261
Bluegill	P	178	0.861	52	0.519	591	3.152
Rock bass	P	173	0.837	76	0.759	37	0.197
Brook silverside	-	158	0.764	80	0.799	87	0.464
Brown bullhead	P	120	0.581	6	0.060	9	0.048
Northern pike	P	113	0.547	42	0.419	8	0.043
Johnny darter	-	109	0.527	236	2.356	483	2.576
Bowfin	P	70	0.339	13	0.130	3	0.016
Tadpole madtom	-	55	0.266	16	0.160	17	0.091
Grass pickerel	-	50	0.242	4	0.040	1	0.005
Lake chubsucker	P	46	0.223	1	0.010	-	-
Yellow bullhead	P	35	0.169	7	0.070	1	0.005
White sucker	-	18	0.087	6	0.060	22	0.117
Black bullhead	P	17	0.082	2	0.020	1	0.005
Carp	-	15	0.073	8	0.080	-	-
Slimy sculpin	P	9	0.044	-	-	-	-
Rainbow smelt	-	7	0.034	10	0.100	15	0.080
Gizzard shad	-	7	0.034	1	0.010	2	0.011
Warmouth	-	6	0.029	2	0.020	-	-
Smallmouth bass	P	5	0.024	14	0.140	6	0.032
Trout-perch	-	4	0.019	15	0.150	30	0.160
Emerald shiner	-	3	0.015	466	4.653	128	0.683

Table 31. Continued.

Species	1972	1977		1978		1979	
		total no.	% of total	total no.	% of total	total no.	% of total
Banded killifish	-	2	0.010	51	0.509	9	0.048
Rainbow trout	-	2	0.010	6	0.060	-	-
Goldfish	-	2	0.010	1	0.010	2	0.011
Golden redhorse	-	1	0.005	1	0.010	-	-
Bigmouth shiner	P	1	0.005	-	-	-	-
Cisco	-	1	0.005	-	-	-	-
Coho salmon	-	1	0.005	18	0.180	3	0.016
Blacknose shiner	-	1	0.005	-	-	-	-
Lake trout	-	1	0.005	7	0.070	-	-
Pirate perch	P	1	0.005	-	-	-	-
Burbot	-	1	0.005	-	-	-	-
Longnose dace	-	1	0.005	-	-	-	-
Quillback	-	1	0.005	-	-	-	-
Mottled sculpin	-	1	0.005	4	0.040	72	0.384
Channel catfish	-	1	0.005	-	-	-	-
Ninespine stickleback	-	1	0.005	43	0.420	9	0.048
Chinook salmon	-	-	-	3	0.030	12	0.064
Fathead minnow	P	-	-	3	0.030	15	0.080
Shorthead redhorse	-	-	-	3	0.030	-	-
Creek chub	-	-	-	2	0.020	-	-
Common shiner	-	-	-	2	0.020	4	0.021
Blackside darter	-	-	-	1	0.010	2	0.011
Sand shiner	-	-	-	2	0.020	17	0.091
White crappie	-	-	-	1	0.010	-	-
Central mudminnow	P	-	-	1	0.010	-	-
Iowa darter	-	-	-	1	0.010	-	-
Longnose sucker	-	-	-	-	-	13	0.069
Unidentified coregoninae	-	-	-	-	-	5	0.027
Logperch	-	-	-	-	-	3	0.016
Brown trout	-	-	-	-	-	1	0.005
		20667		10015		18750	

More alewives than any other species were collected in Pigeon Lake during the 3-yr study with a total of 12,877 individuals caught. Alewives comprised 34, 6, and 28% respectively of the 1977, 1978, and 1979 catches. Most fish were YOY seined at stations S (Lake Michigan influenced) and V (undisturbed Pigeon Lake) in July and August. Pigeon Lake apparently provides a good nursery area for alewives. The reason for the relatively low catch of alewives (particularly YOY) in 1978 is not known. Data for the entire vicinity (including Lake Michigan) of the Campbell Plant show that the 1978 year class was a relatively small one. Interestingly, the catch of emerald shiners, fish that have been suspected to be outcompeted by alewives when both species occupy the same area, correlates negatively with catch of alewives (Table 31).

Pigeon Lake also serves as an important nursery area for spottail shiners. Most caught in Pigeon Lake were YOY seined from July through October at station S. Despite the decline from 1977 to 1978, the population of spottail shiners in Pigeon Lake remained relatively stable during our 3-yr study.

The preferred spawning site for golden shiners was determined to be station T (Pigeon River influenced) where substantial numbers of YOY golden shiners were seined in July 1977. In 1978 adult golden shiners were seined in relatively high numbers in April and May, but in 1979 there was a drastic decrease in golden shiner catch which may be due to competition from yellow perch at station V.

The yellow perch population in Pigeon Lake appeared to be stable between 1977 and 1978 (this population is believed to be distinct from the Lake Michigan yellow perch population). However, in 1979 the perch catch in Pigeon Lake increased dramatically due mainly to high catches of YOY yellow perch (over 6400 YOY fish) in June and July at station V (undisturbed Pigeon Lake). Reasons for such a large year class are not known. Perhaps the reduction in numbers of predators allowed for greater survival of larvae. Numbers of northern pike caught declined steadily from 1977 to 1979. In 1977, many pike were caught in the river-influenced area of Pigeon Lake, while in 1978, with the elimination of stations Y and T, catch declined. Note that in 1977 and 1978 most pike were caught in bottom gill nets. With elimination of station M, catch declined again in 1979. Estimates from the mark and recapture study showed that the population of large (>299 mm) northern pike was stable between 1977 and 1978 and that the population of smaller (<299 mm) pike increased from 1977 to 1978. In 1979 not enough pike were captured to estimate population size, but observations while electroshocking seemed to indicate that the population had declined. This may be due to illegal gillnetting activity during 1979 (R. Lincoln, personal communication, Michigan Dept. of Natural Resources, Grand Rapids, Mich.). At least one gill net was removed from Pigeon Lake by MDNR conservation officers.

Largemouth bass catches declined steadily from 1977 to 1979. In 1977 most largemouth bass caught were YOY seined at station T, while in 1978 and 1979 most bass were YOY seined at station V. The mark and recapture study showed that the population of largemouth bass greater than 219 mm in Pigeon Lake declined significantly between 1977 and 1978. Angling pressure and competition from other large predaceous fish in Pigeon Lake were possible reasons for the decline. Not enough largemouth bass were electroshocked in 1979 to estimate the population, but by observation, the population appeared to have declined further between 1978 and 1979. Perhaps competition from yellow perch (including the large year class of 1979) reduced the largemouth bass YOY

numbers at station V. The Pigeon Lake survey (see RECREATIONAL AND COMMERCIAL USE) showed that most anglers felt the largemouth population had declined from 1977 to 1979.

Most anglers also felt panfish populations, particularly bluegills, were reduced in recent years. Preferred habitat of pumpkinseeds appeared to be the weedy area of station T based on our 1977 sampling. A substantial number of pumpkinseeds caught during 1977 and 1978 were YOY. The low catch of pumpkinseeds in 1979 may have been due to competition from bluegills; all bluegills collected in 1979 (591 fish) were YOY. The reason for the decline in black crappies caught between 1978 and 1979 may have been competition from yellow perch adults and YOY.

The bluntnose minnow was a major species in Pigeon Lake during 1977-1979. A substantial number of bluntnose minnows were collected at station T during 1977 and thus a drop in catch between 1977 and 1978 was expected after station T was deleted. The bluntnose minnow population appeared to be fairly stable in Pigeon Lake despite the decrease in catch between 1978 and 1979.

The brook silverside is very common at station T as well as station V and its population throughout the lake appeared to be quite stable between 1977 and 1979. The tadpole madtom is most abundant in the riverine area of Pigeon Lake and its population in the lake has not changed drastically during the study years. This is probably also true of the rock bass population in spite of the decline between 1978 and 1979. Species which are common in the Pigeon River-influenced area of Pigeon Lake, but not elsewhere in the lake, included grass pickerel, lake chubsucker, yellow bullhead, brown bullhead, and black bullhead.

The johnny darter catch in Pigeon Lake increased steadily from 1977 to 1979. Almost all fish caught were seined at stations S and V. Perhaps the slight change in location of beach station S which was moved closer to Lake Michigan during 1978 influenced the change in catches between 1978 and 1979. The bowfin population in Pigeon Lake is probably quite stable; the decrease in catch from 1977 to 1979 reflects changes in the sampling scheme during the 3 yr of the study.

Alewife

Alewives are only transient occupants of Pigeon Lake, apparently using the lake as spawning and nursery grounds. Adult alewives move into Pigeon Lake in spring and early summer. Bottom gill nets set at station M (influenced by Lake Michigan) in 1978 caught 7 adult alewives in April, 112 in June, and 119 in July. Most fish collected in June had well developed gonads; in July, most were ripe-running or spent. By August, adult alewives had moved out of Pigeon Lake. In 1977, low numbers of alewives were caught in June. These fish were probably remnants of a larger spawning population that may have left the lake prior to the start of sampling that year.

In 1977, alewife larvae, which appeared to be recently hatched, were collected during early June. No sampling was done prior to June, so documentation of first appearance of larval alewives was not possible. Densities of alewife larvae decreased in late June, indicating a tapering off of spawning. Young-of-year (YOY) alewives first appeared in July at beach stations S (influenced by Lake Michigan), T (influenced by Pigeon River), and V (undisturbed Pigeon Lake). Numbers of fish seined were 428, 10, and 6324 respectively. The extreme eastern portion of Pigeon Lake and the Pigeon River

(station T area) did not appear to be preferred alewife spawning and nursery habitat as evidenced by the relatively low catch of YOY there. In August and September, all but one YOY were collected at beach station S. By October, no YOY were collected. They had either moved into deeper water in Pigeon Lake or moved out into Lake Michigan.

In 1978, high densities of larval alewives were observed in Pigeon Lake in early June. However, densities of alewife larvae decreased dramatically in late June. Catches of YOY alewives in Pigeon Lake were much lower than in 1977. Only 336 YOY alewives were collected from July to November at beach stations S and V. Most (318) were taken in July at station S. This apparent year-class failure of alewives in Pigeon Lake was not due to lack of adults moving in to spawn; adults were caught in June and July. The lack of alewife YOY was accompanied by an increase in catches of emerald shiner, a competing species (Jude et al. 1979a).

Early June 1979 sampling indicated that larval alewives were noticably rare at Pigeon Lake beach stations. However, by late June, densities of alewife larvae increased markedly. Alewife YOY were more abundant in 1979 than in 1978. They first appeared in August, as compared to July in 1977 and 1978. Water temperatures during 1979 were generally cooler than in the previous 2 yr, which may have delayed spawning or growth to the point where alewives were too small to be recruited to our fish sampling gear until August. At beach station S (influenced by Lake Michigan) in August, 1138 YOY alewives were collected, while at beach station V (undisturbed Pigeon Lake), 3690 YOY were caught. Few alewives overwinter in Pigeon Lake. As winter approaches, they move into deeper water, probably seeking slightly warmer temperatures available at greater depths in Lake Michigan.

Gizzard Shad

Few adult gizzard shad were collected in Pigeon Lake during the 3 yr of our study: seven in 1977, one in 1978, and two in 1979. According to Scott and Crossman (1973), the Great Lakes area is at the northern limit of gizzard shad distribution, which in part explains their low abundance. Temperature is an important factor for this species. Shad often become a nuisance because of their attraction to areas near power plant thermal effluents where otherwise temperatures may be too cool for them (Bodola 1966). Large populations exist in the nearby Grand River, and specimens we collected in the fall may have migrated from the river. In addition, a localized population of shad also lived in the discharge canal of the Campbell Plant.

Few larval gizzard shad were collected in Pigeon Lake. Gizzard shad larvae are difficult to distinguish from alewife larvae. However, due to the greater abundance of adult alewives compared to adult gizzard shad, we feel that few gizzard shad larvae were present in Pigeon Lake. Seven larval gizzard shad were identified in 1979 and all were collected from openwater areas of Pigeon Lake.

Largemouth Bass

In North America the native range of largemouth bass extends from southern Ontario and Quebec throughout the Great Lakes and the Mississippi Valley and south to Florida and northeastern Mexico (Mraz et al. 1971). Introductions to farm ponds have extended the range of the largemouth bass westward. In the

Great Lakes basin, largemouth bass are widely distributed in shallow, weedy lakes and river backwashes (Mraz et al. 1971), usually at depths less than 6 m (Becker 1976). In Pigeon Lake and throughout their range bass are highly regarded as a sport fish.

Largemouth bass reach sexual maturity at 3 to 5 yr of age when fish are approximately 300 mm (Scott and Crossman 1973). Spawning takes place from late spring to midsummer, with a peak of spawning activity in early or mid-June (Scott and Crossman 1973). Nesting sites, usually situated in sand and gravel, are prepared by males when water temperatures reach 16.7 to 18.3 C (Mraz et al. 1971). Male bass aggressively guard their nests until the eggs have hatched. Usually hatching occurs 3 to 7 days after fertilization. In Pigeon Lake largemouth bass spawn in late May-early June (Jude et al. 1978, 1979a, 1980). Preferred spawning habitat is the area near beach station T (influenced by Pigeon River), while considerably less extensive spawning occurs near undisturbed Pigeon Lake stations V and X. Densities from 260 to 598 bass larvae per 1000 m^3 were collected between the first of June and the end of July 1977 at station T. At station X, densities from 25 to 1000 larvae per 1000 m^3 were sampled in October 1977 and June 1978 respectively. As many as 273 YOY largemouth were caught at beach station V in 1977. These areas support extensive macrophytic growth; station T surpasses stations V and X in density of vegetation and in remoteness from disturbance caused by boat traffic and construction-related activities. Bass fry spawned in Pigeon Lake feed on an abundant supply of amphipods. By mid-July YOY bass have grown to about 50 mm. Bass fry disperse to other areas of the lake and expand their diets to include microcrustacea such as <u>Daphnia</u>, <u>Limnocalanis</u>, <u>Pontoporeia</u>, and <u>Hyallela</u> and insects such as corixids and odonates. Larger bass also eat crayfish and forage fish such as golden shiners. Elliott (1976) found that largemouth bass fry feed throughout the day, but are inactive and closely aggregated in one location at night. Natural mortality, including predation and disease, diminishes numbers of largemouth fry as summer progresses.

Jude et al. (1978, 1979a, 1980) collected largemouth bass in seine and gill net samples in water from 9.0 to 27.3 C. During summer most bass appeared to prefer water of about 20 C. Scott and Crossman (1973) reported that bass in field studies preferred water temperatures between 26.6 and 27.7 C, but Becker (1976) stated that the species was most active between 15.6 and 24.4 C. Larger fish are better able than smaller fish to behaviorally regulate temperature by moving to different parts of the lake. Areas of Pigeon Lake which are influenced by Lake Michigan (such as stations M and S) are consistently cooler (by 1 to 7 C) than lake areas which do not mix with Lake Michigan waters (such as stations T and V). Growth of bass is closely related to temperature. Niimi and Beamish (1974) found that when largemouth bass were fed to satiation, best growth was achieved at 18 C (where metabolic requirements are decreased). Food may be limited in Pigeon Lake due to presence of several predaceous fish, so water temperatures favorable to bass growth would occur roughly between 15 and 20 C. Such temperatures occur during about 4 mo of the year at beach station V compared with about 2 mo of the year at beach station S (influenced by Lake Michigan). Growth of largemouth bass (Table 32) was about average in Pigeon Lake compared with bass growth in lakes listed by Carlander (1977). The overall condition factor for bass in Pigeon Lake (K = 1.4) was also about average compared with data from other lakes.

We estimated population number and density of largemouth bass in Pigeon Lake from mark and recapture studies conducted in 1977 and 1978. The 1978

estimate for 175-220-mm bass was 1132. The portion of the bass population greater than 220 mm declined from 471 to 290 between 1977 and 1978, and interviews with fishermen indicated that better than average angling success may have been partially responsible for the decline in bass numbers. Bass density in Pigeon Lake in 1978 was calculated at 2.6 kg/ha, which is quite low compared with densities of largemouth bass in lakes catalogued by Carlander (1977). Competition from other predaceous fish along with mortality due to angling are thought to be reasons for the low density of bass in Pigeon Lake.

Largemouth bass occupy deeper sections of Pigeon Lake during April, then move to shallow water in May. Bass move around the lake quite freely during summer, then return to deeper water around October and November and remain there until the following spring.

TABLE 32. Age and growth of largemouth bass collected from Pigeon Lake, Port Sheldon, Michigan, 1977 and 1978 combined (standard error in parentheses).

Age	Total length range (mm)	Mean length (mm)	Number examined
0 (1st summer of life)	41-162	80 (2)	115
1	70-250	147 (4)	91
2	106-337	214 (7)	62
3	151-390	284 (10)	39
4	253-429	345 (8)	28
5	338-442	382 (8)	18
6	376-445	397 (10)	7
7	411-419	415 (4)	2

Northern Pike

Northern pike are native to North America and through widespread introductions are now found throughout the northern hemisphere (Scott and Crossman 1973). Northern pike are frequently found in cool to warm lakes, ponds, and sluggish rivers. They often prefer shallow, weedy areas during spring and fall and deeper, cooler water during summer (Hubbs and Lagler 1964). Much of the Pigeon Lake-Pigeon River area is suitable pike habitat, and northern pike is an important predator in the ecosystem. Because of their abundance, northern pike from Pigeon Lake have been collected for use as spawning stock by Michigan Department of Natural Resources (MDNR) personnel (John Trimberger, personal communication, MDNR, Grand Rapids, Mich.).

Northern pike generally spawn just after ice leaves, and spawning has been reported during April in Michigan (Carbine 1942). Early April spawning by northern pike in Pigeon Lake is indicated from data collected by Jude et al. (1978, 1979a, 1980). Pike spawn during daylight on heavily vegetated floodplains of rivers and marshes (Scott and Crossman 1973). Such areas are best represented in Pigeon Lake by beach station T (influenced by Pigeon River) and V (undisturbed Pigeon Lake). Pike eggs adhere strongly to vegetation until

they hatch in 12-14 days. Due to mortalities as high as 99.8% for pike eggs and larvae, the number of young pike leaving the spawning grounds is very low compared to the number of eggs spawned. Population studies of pike in Pigeon Lake during 1977 and 1978, however, documented excellent recruitment of 1-yr-old pike between 175 and 300 mm, indicating that Pigeon Lake provides conditions favorable for pike reproduction.

After hatching, pike larvae often attach themselves to vegetation (by means of adhesive glands on the head) until their yolk sacs have been absorbed (Scott and Crossman 1973). Free-swimming YOY grow rapidly on a diet of large zooplankton and, after only about 1.5 wk, they begin feeding on other fish. At a length of about 50 mm, young pike are almost totally piscivorous (Scott and Crossman 1973). Larger pike in Pigeon Lake feed on many fish species, the most prominent of which are spottail shiner, gizzard shad, alewife, yellow perch and largemouth bass (Jude et al. 1980). Of species eaten, largemouth bass, spottail shiner, and yellow perch are resident populations in Pigeon Lake; whereas, alewives present in Pigeon Lake appear to be mostly transient (spawning) segments of primarily Lake Michigan populations. Gizzard shad, on the other hand, seem to be Lake Michigan or Grand River residents and are rarely present in Pigeon Lake. Through 3 yr of field collections, Jude et al. (1978, 1979a, 1980) caught only 10 gizzard shad in Pigeon Lake. The relatively large number of shad eaten by northern pike therefore implies that some pike may leave Pigeon Lake to forage in Lake Michigan. Support for this contention comes from the capture of two northern pike in Lake Michigan gill nets (Jude et al. 1979a), recapture in Lake Macatawa of a pike tagged in Pigeon Lake (Lake Macatawa is located approximately 16 km south of Pigeon Lake by way of Lake Michigan), and reports of ice fishermen catching pike near the jetties connecting Pigeon Lake with Lake Michigan. In any case, the ability of northern pike to utilize a wide forage base contributes to favorable population levels in Pigeon Lake. Compared to fish in lakes listed by Carlander (1969), pike in Pigeon Lake showed average to good growth (Table 33), an average condition factor ($K = 0.61$), and high density (7.2 kg/ha). Growth and gonadal development of some YOY pike in Pigeon Lake progressed to the extent that they were expected to spawn after just 1 yr. Such rapid development has previously been noted in Carlander (1969), but is generally considered exceptional.

Pike have been caught in Pigeon Lake at water temperatures from 1.8 to 27.3 C (Jude et al. 1978, 1979a, 1980). Becker (1976) reported peak northern pike activity at water temperatures between 12 and 23 C, and temperatures in this range generally characterize Pigeon Lake from May through October.

Numbers of two sizes of Pigeon Lake pike were estimated and we found that the number of pike greater than 299 mm was stable between 1977 and 1978 at approximately 680. Stability is attributable to adequate forage, suitable habitat, and low mortality (either natural or angling). Pike between 175 and 299 mm increased from about 630 in 1977 to approximately 1260 in 1978. This represents good reproduction and recruitment of northern pike in Pigeon Lake.

Table 33. Age and growth of northern pike collected from Pigeon Lake, Port Sheldon, Michigan, 1977 and 1978 combined (standard error in parentheses).

Age	Total length range (mm)	Mean length (mm)	Number examined
0 (1st summer of life)	93-285	202 (5)	58
1	204-517	313 (5)	133
2	296-672	429 (8)	90
3	340-727	514 (11)	62
4	420-793	575 (14)	40
5	486-818	648 (15)	27
6	594-829	713 (18)	12
7	625-820	717 (40)	4
8	739	739 (0)	1

Yellow Perch

Yellow perch is a widespread percid, occurring throughout North America. Its native range extends from the Atlantic coast (Nova Scotia to Florida) north and westward to Alberta, including the entire Great Lakes drainage basin. Introductions have established populations throughout the western and southwestern United States and in British Columbia (Scott and Crossman 1973). Yellow perch is a highly adaptable species inhabiting a variety of waters, including large and small clear lakes and quiet rivers with moderate vegetation. Kitchell et al. (1977) described typical percid habitat as large temperate rivers and lakes with shallow to moderately deep zones and extensive littoral and shoreline areas characterized by sand or gravel substrates, submerged vegetation, low current velocity, temperatures conducive to spawning and growth, and well oxygenated spawning substrates. Pigeon Lake provides many of these features.

Yellow perch were taken during field sampling in Pigeon Lake in the months April through December 1977-1979 (Jude et al. 1978, 1979a, 1980), and observations of ice fishing indicated adult perch were remaining over winter at least in the 2-3 m deep area south of station V (undisturbed Pigeon Lake). Mature yellow perch require several months of cold temperatures (4-10 C) for successful gonad development (Jones et al. 1977), conditions which are met in the deeper areas of Pigeon Lake. As water temperature increased from April to June, adult and yearling perch catches increased at beach stations S (Lake Michigan influenced) and V. Gonad conditions of captured fish indicated spawning was occurring in April and May, as Pigeon Lake beach stations reached suitable spawning temperatures (8.9-12.2 C, Scott and Crossman 1973). McCauley (1977) found that preferred temperatures of yellow perch varied by season, with a final preferendum of 24 C in spring. Water temperatures as high as 24 C do not occur until June or later in Pigeon Lake. However, water temperatures are commonly 1 to 7 C warmer and less variable at stations V (undisturbed Pigeon Lake) and T (Pigeon River) than at Lake Michigan-influenced beach station S.

Warmer temperatures at stations V and T probably encourage perch to concentrate in these areas in spring and early summer. Stations V and T also support heavier macrophyte growth and exhibit more extensive shallow areas than station S. These features make the areas around stations V and T suitable for perch spawning and growth of young perch. In addition, these areas of Pigeon Lake and Pigeon River are well sheltered from high winds and waves by sand dunes and forested hills between Pigeon Lake and Lake Michigan. Adverse weather has been documented as a destructive factor in yellow perch spawning areas on a large lake (Clady 1976).

Yellow perch larvae were observed in plankton net samples in Pigeon Lake in May and June, with maximum densities found at Pigeon River beach station T in 1977 (2820/1000 m^3) and undisturbed Pigeon Lake beach station V in 1978 (15,400/1000 m^3). Perch larvae were also abundant in 1979 at station V (6360/1000 m^3) and openwater station X (41,873/1000 m^3). These larvae were apparently the result of perch spawning at stations V and T. Lower densities of perch larvae were noted at beach station S and Pigeon Lake station M. These larvae exhibited length frequencies similar to those of larvae sampled at Lake Michigan stations (Jude et al. 1978, 1979a, 1980). Thus most larvae in the vicinity of stations S and M probably were drawn into Pigeon Lake from Lake Michigan with the flow of J.H. Campbell Plant cooling water.

Yellow perch in Pigeon Lake grew rapidly in their first year. Hatching at about 5 mm (Scott and Crossman 1973), YOY perch ranged from 15 to 34 mm in June, and some individuals exceeded 50 mm by July and 100 mm by August and September. These values correspond well with values given by Trautman (1957), who reported that perch in Ohio ranged from 46 to 102 mm by October. McCormick (1976) determined that maximum growth rate for YOY yellow perch occurred at 26-30 C. In Pigeon Lake temperatures of 26 C or higher were observed only at station V in August, but temperatures of 20-24 C were common at stations V and T through the summer, providing conditions favorable for growth.

Scales were collected from 36 yellow perch taken by electroshocking in Pigeon Lake in November 1979. Examination of scale annuli revealed most perch (27 fish) were age 2 (past their third summer of life) and ranged in length from 162 to 215 mm at time of capture. Only six fish were age 1 (127-155 mm) and three were age 3 (179-216 mm). Back calculations of length at age, using the Dahl-Lea method (Lagler 1956), revealed no significant differences (α = 0.05) in length at age among male, female and unsexed perch (Fig. 15). Accordingly mean length (standard error) at age was calculated for perch regardless of sex and is given as: age 1-69 mm (2.6); age 2-136 mm (2.7); age 3-162 mm (8.5). Rapid growth was evident for age-1 fish and continued for age-2 fish. Growth of age-3 fish was apparently much slower; however, low sample size for this group (two males and one unsexed perch) reduces confidence in age-3 results.

Survival of YOY yellow perch was not consistent in Pigeon Lake from 1977 through 1979. Moderate numbers of larval and YOY perch were observed at station T (Pigeon River) throughout 1977 (Jude et al. 1978). While perch larvae were abundant at station V (undisturbed Pigeon Lake) in May and June 1978, few YOY perch were observed that year (Jude et al. 1979a). In contrast, similar densities of larval perch at station V in 1979 were followed by exceptional abundance of YOY perch from June through September (Jude et al. 1980). Thus, it appeared that reduction in survival of yellow perch larvae in June and July 1978 was a major factor contributing to absence of YOY perch from Pigeon Lake samples that year.

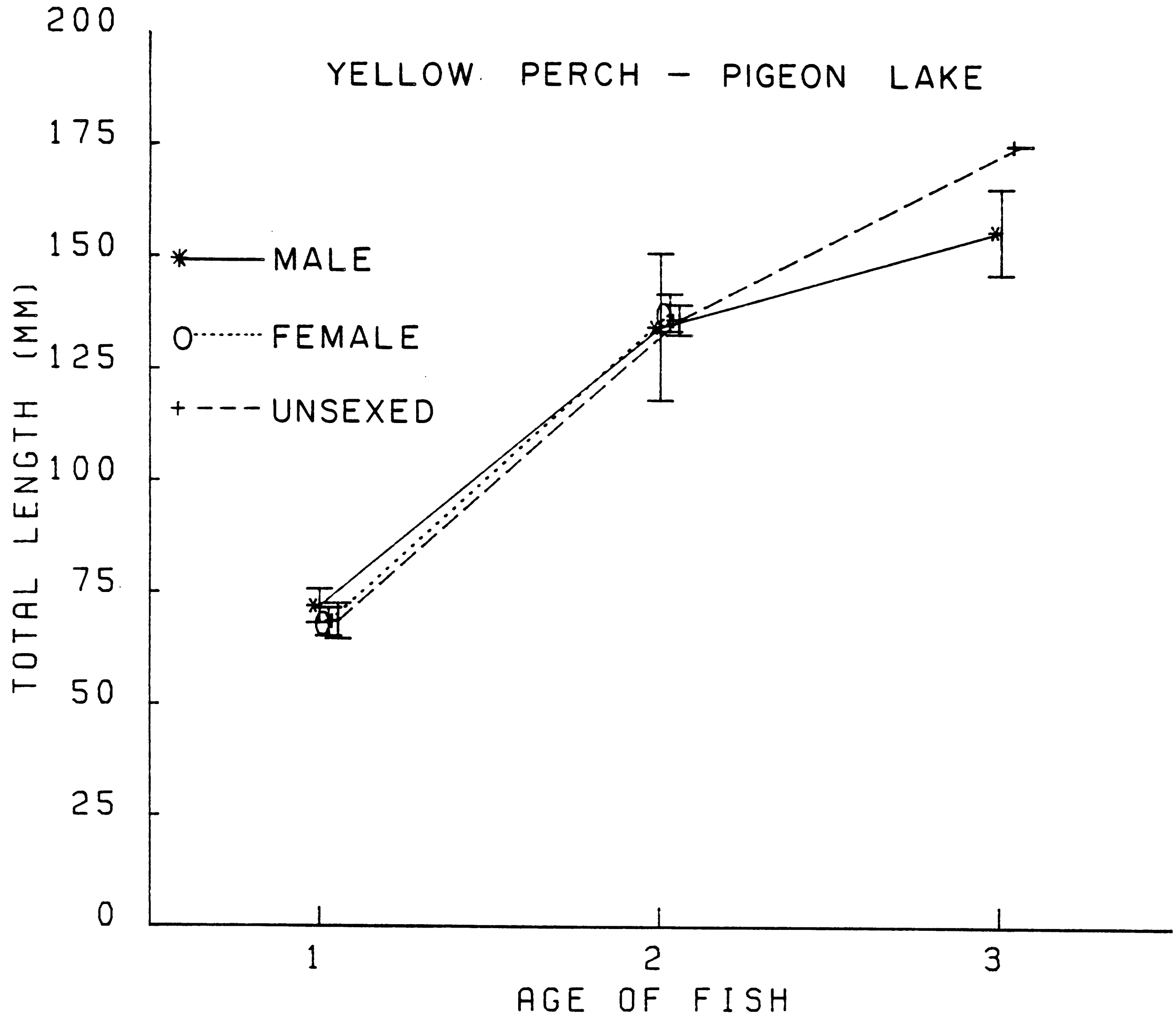

Fig. 15 . Total length as a function of age for male, female and unsexed yellow perch taken from Pigeon Lake, November 1979. Values are mean length ± 1 standard error.

Fluctuations in abundance of yellow perch have been noted for many perch populations (e.g., Hile and Jobes 1940, Jobes 1952, Wells 1977), and survival of YOY perch has been indicated as a primary factor in some cases. Noble (1975) indicated that reduced zooplankton abundance in Lake Oneida, New York, caused reduced growth of YOY perch, resulting in lower survival of perch since piscivorous predators such as walleye consumed greater numbers of smaller perch. Alm (1952) suspected predation by mature perch on YOY perch to be a major factor causing year-class failure in several small lakes. Pigeon Lake supports populations of northern pike, bowfin, and largemouth bass, also known to prey on young perch. Northern pike of 175-299 mm increased from 630 in 1977 to about 1260 in 1978 in Pigeon Lake and may have been a major factor in reducing perch survival.

Other studies have explored the relationship between environmental variables and yellow perch year-class abundance. Jobes (1952) found significant correlations between perch abundance and mean monthly temperatures during the summer growth period in Lake Erie, but Jobes (1952) and Doan (1942) found no significant correlations between perch abundance and various other meteorological and limnological variables. Temperatures taken at time of seining in Pigeon Lake for 1977 through 1979 do not show remarkable differences among years, and no conditions of extreme weather were noted to explain the apparent differences in survival, although it is possible some adverse events occurred between sampling dates and were not observed. One possible causal factor was increased boat traffic and associated activity in Pigeon Lake, as docks were constructed and areas dredged to provide shelter for construction vessels used on Lake Michigan. However, almost all this activity took place near station S (Lake Michigan influenced) and probably did not have much effect on conditions at station V (undisturbed Pigeon Lake) where spawning was notably successful in 1979. Whatever the reason for lack of success by yellow perch in Pigeon Lake in 1978, exceptional year-class abundance in 1979 indicated that Pigeon Lake still provided viable habitat for yellow perch.

As yellow perch increase in size, food changes from zooplankton to immature aquatic insects, larger invertebrates, small fishes, and the eggs and young of a wide variety of fish (Scott and Crossman 1973). In turn, adult perch fall prey to a variety of other Pigeon Lake fish and water birds such as gulls, mergansers, loons, herons, and kingfishers (Scott and Crossman 1973). Additionally, yellow perch is highly regarded as a sport fish. Our survey of Pigeon Lake recreational users undertaken in early 1980 indicated that winter fishing for yellow perch was a major recreational use of Pigeon Lake, with over 8000 yellow perch taken in 1979.

Smallmouth Bass

Smallmouth bass, originally restricted to east-central North America, now occur everywhere in the United States following extensive introductions which began in the mid-1800s (Scott and Crossman 1973). It is a prized sport fish throughout its range.

Smallmouth bass spawn from late May to early July at water temperatures between 13 and 20 C. Males build nests on sandy, gravelly, or rocky bottoms, usually near the protection of rocks or logs and occasionally near dense vegetation (Scott and Crossman 1973). Four to 10 days after fertilization, larvae 5.6-5.9 mm hatch. Within 12 days yolk sacs have been absorbed and

larvae which have grown to between 8.7 and 9.9 mm rise from the bottom into the water column. In Pigeon Lake, limited evidence suggests smallmouth spawning occurred in early to mid-July in 1977 and early June in 1978. Low densities of smallmouth bass larvae were collected at Pigeon Lake beach station S (influenced by Lake Michigan) and openwater station X (undisturbed Pigeon Lake). The small number of larvae sampled leave some doubt as to whether these bass were spawned in the areas of capture or whether they had migrated to these areas after hatching. Twenty-five adult and juvenile smallmouth bass ranging from 38 to 435 mm were collected throughout Pigeon Lake at stations T (influenced by Pigeon River), V (undisturbed Pigeon Lake), and M and S (both influenced by Lake Michigan). No adult caught had anything beyond moderately developed gonads.

Initial diet of young smallmouth bass consists of small crustaceans. Larger fish feed on fish, crayfish, insects (larvae and adults), and frogs (Schneberger 1972). Smallmouth bass are inactive and feed little during winter (Scott and Crossman 1973). Growth of smallmouth bass in Pigeon Lake is probably good due to availability of suitable food.

Preferred temperatures of smallmouth bass in the field fall between 20.3 and 21.3 C (Scott and Crossman 1973). In Pigeon Lake this species has been caught between 11 and 20 C.

Because of their visual acuity and behavior, juvenile and adult bass (both largemouth bass and smallmouth bass) are generally able to avoid entrapment in various sampling gear. A preference for cooler temperatures and less dense vegetation, compared with largemouth bass (Becker 1976), makes smallmouth bass the more difficult of these species to capture in seines. Abundance of smallmouth bass in Pigeon Lake therefore, is difficult to assess. Some smallmouth bass were tagged during mark and recapture experiments, but not enough to estimate population size. However, suitability of habitat and availability of food probably ensure a viable smallmouth bass population in Pigeon Lake.

Johnny Darter

The johnny darter is a member of the perch family and is widely distributed throughout the Lake Michigan basin (Becker 1976). Johnny darter populations in Pigeon Lake are represented by two distinct forms, the central johnny darter, *Etheostoma nigrum nigrum* Rafinesque and the scaly johnny darter, *Etheostoma nigrum eulipis* (Hubbs and Greene 1935). A preliminary examination of Pigeon Lake johnny darters revealed that the majority of the population contained intergrades and pure scaly johnny darters with a few central johnny darters. It is not certain at this time if any ecological differences exist between the two forms, but scaly johnny darters seem to prefer weedy, soft bottoms like those of undisturbed Pigeon Lake station V over the sandy, less vegetated station S (Lake Michigan influenced). In the present study no distinction between the two forms will be made; all will be considered *Etheostoma nigrum*.

During 1977, when sampling began in June, 109 johnny darters were caught in Pigeon Lake. All were seined at beach stations S (influenced by Lake Michigan), T (influenced by Pigeon River), and V (undisturbed Pigeon Lake) with catches of 30, 25, and 54 respectively. The majority (98) were between 40 and 70 mm in length and were probably age 1 and 2 (Jude et al. 1978).

In 1978 236 johnny darters were seined in Pigeon Lake. All were caught at beach stations V (undisturbed Pigeon Lake) and S (Lake Michigan influenced) with catches of 127 and 109 respectively. August was the month of maximum catch in 1978 when 78 fish were caught. Size range of the darters caught in 1978 was 25-74 mm; 87% were between 35 and 65 mm. Spawning occurred from late April to mid-May in 1978.

A 105% increase in the johnny darter catch occurred between 1978 and 1979; 483 were caught in 1979. The size range was 20-80 mm; 85% were between 45 and 65 mm. September was the month of maximum catch (137 fish); 111 of these darters were caught at beach station S indicating that a large school was present there which may explain part of the increased 1979 catch. Johnny darters spawned during May to mid-July in 1979 in Pigeon Lake. Preferred temperatures for this species in Pigeon Lake during 1977, 1978, and 1979 were 11-19 C, 11-25 C, and 11-19 C respectively. Johnny darter abundance at Pigeon Lake beach stations is more dependent on time of year than water temperature.

Although adult johnny darters are very abundant in Pigeon Lake, their larvae were seldom collected. Since the benthic johnny darter spawns under rocks, logs, and other objects (Winn 1958a, 1958b) and the young are guarded by adults, our gear may be ineffective in sampling the young of this species. Eleven darter larvae were caught in Pigeon Lake in 1977. Eight were identified as johnny darter larvae and three as *Etheostoma* spp. No darter larvae were caught in Pigeon Lake during 1978. Five johnny darter larvae were caught in Pigeon Lake during 1979. These larvae, 4.6 to 22.5 mm, were collected from May to July. Densities at station S were 553/1000 m^3.

Sunfishes

Introduction--

Six species of Centrarchidae (other than *Micropterus* spp. -largemouth and smallmouth bass, which are discussed elsewhere) were collected in Pigeon Lake during 1977-1979. These included bluegill, black crappie, pumpkinseed, rock bass, warmouth, and white crappie. Green sunfish were collected in impingement samples taken at the J.H. Campbell Plant in 1978, suggesting their presence in Pigeon Lake.

Bluegill--

Bluegill was the most abundant species of sunfish collected during the 3 yr of sampling. Of 821 bluegills collected, 786 were YOY. Most sampling in Pigeon Lake was with beach seines which would effectively sample YOY in shallow nursery areas. Adult bluegill would be more able to avoid capture in seines.

Bluegills prefer shallow water with rooted vegetation (Snow et al. 1970). The eastern portion of Pigeon Lake, which includes beach stations V (undisturbed Pigeon Lake) and T (influenced by Pigeon River), is typical shallow, weedy bluegill habitat. Most bluegills were caught at these stations, although station T was not sampled after 1977.

Although few bluegill larvae were identified, numerous unidentified *Lepomis* spp. larvae were collected which undoubtedly included bluegill larvae. These larvae first appeared in early June in Pigeon Lake and became more abundant during July and early August, suggesting that spawning began in May and continued into the summer.

Pigeon Lake area residents, responding to a questionnaire, suggested that bluegill and sunfish populations in general have declined in recent years. They attribute the decline to a cooling of Pigeon Lake due to the influx of Lake Michigan water. We have no data to support or refute these observations since our sampling encompassed only 1977-1979.

Black Crappie--

Black crappie was the second-most-common sunfish species collected in Pigeon Lake. As with bluegill, most black crappies collected were YOY. Beach stations V (undisturbed Pigeon Lake) and T (influenced by Pigeon River) appeared to be more favorable crappie habitat as 410 of 478 black crappies were collected there.

Black crappie larvae have been identified from collections in Pigeon Lake. Many larvae were identified as *Pomoxis* spp. and since black crappie is the abundant *Pomoxis* species in Pigeon Lake, we believe most unidentified *Pomoxis* spp. larvae were black crappies. Black crappies spawn in spring, and larval *Pomoxis* spp. first appeared in Pigeon Lake during late May and early June in 1977 and 1978 and during mid-May in 1979.

Pumpkinseed--

During the 3 yr of our study, 369 pumpkinseeds were collected in Pigeon Lake. Catch numbers declined steadily from 232 in 1977 to 114 in 1978 and 23 in 1979. Elimination of beach station T (influenced by Pigeon River) after 1977 was probably a major reason for the lower numbers of pumpkinseeds in our collections. As with the other sunfish species, pumpkinseeds prefer shallow, vegetated areas and the area in eastern Pigeon Lake seems to provide the most suitable habitat.

Only one larva was positively identified as a pumpkinseed. However, numerous unidentified *Lepomis* spp. larvae were collected and some of these are no doubt pumpkinseed larvae. Pumpkinseeds and bluegills have similar spawning times and habitats and, therefore, larvae of both species appear together and are difficult to differentiate at small sizes.

Rock Bass--

We collected 286 rock bass from Pigeon Lake during 1977-1979. Once again, preferred habitat for the species appeared to be the eastern half of Pigeon Lake. Like other centrarchid species, rock bass are nest builders and prefer shallow water with some aquatic vegetation. Catches over 3 yr of sampling were as follows: 173 in 1977, 76 in 1978, and 37 in 1979. The reduction in numbers was probably again due to elimination of sampling at beach station T after 1977 and may also be due to the heavy boat traffic in the western portion of Pigeon Lake during 1979.

Rock bass larvae (nine) were only collected in 1977 at beach station T and during 1978 in some supplementary collections at station T. We did not appear to have sampled prime rock bass spawning and nursery grounds, although collections at station T suggested that this area was suitable habitat.

Warmouth--

Only eight warmouth were collected during the course of our study, six in 1977 (154-192 mm) and two in 1978 (65 mm and 200 mm). They, like other sunfishes, appear to prefer the eastern half of Pigeon Lake. Our collections suggest a small resident population of warmouth in Pigeon Lake, but they are probably not one of the more important centrarchid species in the lake.

White Crappie--

One white crappie was collected in June 1978 in Pigeon Lake. None were caught in 1977 or 1979. Collection of one white crappie documents their presence in the area, but they appear to be rare. Abundant black crappie populations have probably dominated white crappies.

Green Sunfish--

No green sunfish were taken in field collections in Pigeon Lake. However, green sunfish appeared in impingement samples taken at the J.H. Campbell Plant in 1978. This occurrence documents their presence in Pigeon Lake, although their population is probably very small.

Gar

Both spotted and longnose gar have been observed in the Pigeon Lake area, though neither species is common. Pigeon Lake provides a suitable physical habitat for gar, but competition from other fish and mortality of early life stages due to predation probably limit the number of gar in the ecosystem. Although gar eggs are poisonous to mammals and birds, they are apparently not toxic to fish (Scott and Crossman 1973). Juveniles may be subject to relatively heavy predation while larger gar derive considerable protection from their tough, two-layered ganoid scales. Food habits of gar are very similar to those of northern pike. Gar are generally considered an obnoxious species due to their voracious appetites and poor eating quality.

Lake Whitefish

Larval coregonines have been uncommon in the area (including Lake Michigan) during our 3 yr of study. None were collected in Pigeon Lake in 1977 or 1978, but three were observed there in 1979. These larvae, believed to be lake whitefish, were caught during April and May at Pigeon Lake station S (influenced by Lake Michigan). Lake whitefish may have even spawned in the vicinity of the jetties.

Unidentified Coregoninae

Difficulty in identifying species of the genus Coregonus was discussed by Jude et al. (1975, 1978, and 1979a). Most coregonines are believed to be bloater Coregonus hoyi or a hybrid thereof. These coregonines, often called "chubs," were fished commercially until the fishery was closed in 1976, presumably due to overexploitation. They have been increasing in abundance in our Lake Michigan catches over the past 3 yr (Jude et al. 1978, 1979a, 1979b, and 1980).

Bloaters are the smallest of the deepwater ciscoes native to the Great Lakes (Scott and Crossman 1973). Spawning generally takes place in February and March over a variety of bottom types in depths from 36 to 90 m. It is therefore not surprising that they are rare in Pigeon Lake.

Only five coregonines were collected in Pigeon Lake during our 3 yr of sampling. Four small specimens (37-55 mm) were collected by seine in June 1979 at station S, while another, slightly larger individual (60-70 mm) was collected in October. These young fish were most likely YOY.

Spottail Shiner

Introduction--

Spottail shiners are found in shallow areas of large lakes and rivers (Scott and Crossman 1973) and in all of the Great Lakes and many of their tributaries (Hubbs and Lagler 1958). This cyprinid is an important forage species in many larger midwestern lakes and rivers. Spottails were found to be important food items for walleyes (Parsons 1971), northern pike (Hunt and Carbine 1951), and smallmouth bass (Surber 1939). The spottail shiner is a common food item of the northern pike inhabiting Pigeon Lake (Jude et al. 1979a), but was seldom fed on by Lake Michigan piscivores.

Adult Seasonal Distribution--

Although no field samples were collected during winter in Pigeon Lake, spottail shiners most likely inhabit the deepest (western portion) part of the lake. Wells (1968) reported that in the winter spottail shiners in Lake Michigan inhabited deeper water than any other time of year.

In spring spottails began to move into the shallower waters of Pigeon Lake. Collection of adult fish in beach seines coupled with gonad development data (see Jude et al. 1978, 1979a, 1980, - SPOTTAIL SHINERS) indicate that spawning begins in late spring and is completed by early summer in Pigeon Lake. Scott and Crossman (1973) and Peer (1966) reported that spottails spawn on sandy shoals in Lake Erie and Lake Nemeiben, Saskatchewan Dorr (1974b) observed spottails spawning over a water intake crib located at 9 m in Lake Michigan and Jude et al. (1979b) found spottail eggs and larvae concentrated in the Lake Michigan beach zone in the vicinity of the Cook Plant. Relatively few spottail larvae were collected at undisturbed Pigeon Lake station V and Pigeon River influenced station T. Both stations (T and V) (Fig. 1) are characterized by dense growths of aquatic macrophytes and soft muddy bottoms. Spottail shiners definitely prefer a sandy substrate for spawning in Pigeon Lake, as evidenced by large concentrations of spottail larvae at the Lake Michigan- influenced beach station S during 1977, 1978, and 1979.

YOY spottails first appeared in July or August in Pigeon Lake. Almost all were seined at Lake Michigan-influenced station S. This area is a documented nursery area for spottail shiner (Jude et al. 1978). During 1977, 1978, and 1979, the largest monthly catch of spottail shiners was taken in September. YOY and a few yearlings made up the September catch. During October spottail densities began to decrease in the beach zones of Pigeon Lake. A small number of YOY were seined during this month in each year of the study, while even fewer were caught during November. It is suspected that spottails move into the deeper waters of Pigeon Lake during winter months.

Jude et al. (1979a) found that spottail shiners in Lake Michigan selected the warmest water available to them. In Pigeon Lake, however, spottails seemed to select habitat over temperature as evidenced by the large catches at Lake Michigan-influenced station S. Although station V (undisturbed Pigeon Lake) had warmer water temperatures, only a small portion of the Pigeon Lake spottail catch was taken there; even fewer spottails were collected at stations Y and T (Pigeon River influenced) where water temperatures were warmer than station S. Pigeon Lake spottail shiners prefer the sloping fine sand bottom of station S over stations V, T, and Y, which are characterized by dense growths of aquatic macrophytes and a soft peat bottom. Spottail shiners were found in the stomachs of northern pike in Pigeon Lake. Spottail shiners are the most abundant cyprinid in the Lake Michigan-influenced portion of Pigeon Lake. Bluntnose minnows are the most abundant cyprinids in the undisturbed portion of Pigeon Lake, while golden shiners are the dominant cyprinid in the Pigeon River-influenced portion of Pigeon Lake.

Seasonal Distribution of Spottail Shiner Larvae--

Difficulty in identifying cyprinid larvae at the generic level in 1977 led to the classification of all minnows 9 mm or less as unidentified minnows. Increased expertise in larval minnow identification in 1979 led to a drastic reduction in numbers of cyprinids classified as unidentified minnows. The following is an overview of larval cyprinid distribution in Pigeon Lake during 1977-1979. For a more detailed account, see Jude et al. (1979a) - FISH LARVAE AND ENTRAINMENT SECTION - Cyprinid complex. Discussion of seasonal distribution is based on 1979 data.

Spottail larvae were collected in Pigeon Lake from April to September during the study period 1977-1979. No spottails were collected in April and May 1978, suggesting that spawning activity began sooner in 1979. Densities of spottail larvae ranged from 100/1000 m^3 in April to 55,000/1000 m^3 in August. The low percentage of small (6 mm and less) larvae in late August samples suggests that little recent hatching occurred at that time.

A comparison of larvae caught at open water and beach stations indicates that all larvae caught at openwater stations were newly hatched, while beach sampling showed a wider range of sizes. The most likely reason is that smaller larvae are being swept passively from the shoreline areas of Pigeon Lake or drawn from Lake Michigan into the openwater areas; whereas, larger larvae are able to remain in the shallower areas of Pigeon Lake.

Length-frequency data indicate that spawning begins and ends sooner in Pigeon Lake than in Lake Michigan. The west portion of Pigeon Lake (stations S and M) exhibited the highest densities of spottail larvae. This area has been documented as an important spawning and nursery area for spottail shiners in Pigeon Lake (Jude et al. 1979a). Highest densities (55,000/1000 m^3) of spottail larvae were collected at beach station S (Lake Michigan influenced).

Bluntnose Minnow

Introduction--

The bluntnose minnow is distributed throughout the Lake Michigan basin and is the most common inland minnow (Becker 1976). The bluntnose occurs in lakes, ponds, rivers, and creeks and is known to be a valuable forage fish for game fishes (Scott and Crossman 1973). In Pigeon Lake bluntnose minnows were found

in the stomachs of northern pike, largemouth bass, yellow perch, grass pickerel, bowfin, and sunfishes. The slow moving currents and soft bottom of Pigeon Lake provide an excellent habitat for propagation and survival of this fish. Bluntnose minnows are reported to feed primarily on organic detritus and bottom ooze (Heufelder 1976).

Seasonal Distribution--

All but one of the bluntnose minnows caught during our studies were seined. April collections were influenced by water temperature, as evidenced by a decrease in catch from April 1978 to April 1979 when water temperatures were 2.3 C cooler. Highest catch of bluntnose minnows at Lake Michigan-influenced station S occurred in May. Jude et al. (1978) stated that this species spawns during May in Pigeon Lake. Initial indications are that bluntnose minnows probably spawn in the station S area even though the undisturbed Pigeon Lake station V area seems like a more conducive area for bluntnose minnow spawning. After May few bluntnose minnows were caught at Lake Michigan-influenced station S indicating that this sandy bottom habitat was not preferred during summer months. Bluntnose minnows continued to be common in the beach zones of station V (undisturbed Pigeon Lake) and Pigeon River-influenced station T during June and July 1977 when many YOY were captured. During 1979 very few bluntnose minnows were caught in June and July. Water temperatures were similar at station V during June and July 1977, 1978, and 1979. August marked the first major occurrence of YOY in Pigeon Lake. It is likely that YOY remain in the shallows of Pigeon Lake throughout their first summer, being recruited to the sampled population in August due to their increased size. Catch data for September-November suggest there is movement between the beach zones and deeper water. Although the majority of the Pigeon Lake bluntnose minnow population moves to deeper water during autumn and winter months, there is some occasional movement back into shallow areas.

Bluntnose minnows prefer areas of Pigeon Lake that are influenced by the Pigeon River or those unaffected by Lake Michigan. Areas influenced by Lake Michigan water typically exhibited lower abundance of this fish.

Emerald Shiner

The emerald shiner is a pelagic species inhabiting large lakes and rivers (Scott and Crossman 1973). Occurrence of adult emerald shiners in Pigeon Lake exhibited considerable variation during 1977-1979. Scott and Crossman (1973) reported that Lake Erie emerald shiner populations changed considerably from year to year, so a period of low abundance may be followed by one of great abundance. Emerald shiners and alewives probably compete for food and space (Jude et al. 1979a). Both species feed on zooplankton. Larvae and adults of both species inhabit inshore areas at similar times of the year and both species spawn in early summer. Larvae of both species are pelagic. Catch data for adult emerald shiners and alewives showed that in 1977 and 1979, when large numbers of alewives (7094 and 5178 fish) were collected in Pigeon Lake, few emerald shiners were caught (3 and 128 fish). During 1978, however, a reverse trend was observed; 605 alewives and 466 emerald shiners (mostly YOY) were caught.

Nearly all juvenile and adult emerald shiners caught during 1977-1979 were caught at station S (Lake Michigan influenced) at night during the spring or fall. In 1978, from a yearly total of 466 fish, 339 (mostly YOY) were seined at night at station S. In 1979, 105 of the annual total of 128 fish were seined at night during May from station S. Yearlings (20-50 mm, 40 mm modal length) made up the bulk of the catch. The reason the bulk of the emerald shiners were caught at night is probably due to feeding behavior. Gray (1942) indicated that the evening feeding period was most important for emerald shiners in Lake Erie. This species tends to move with its planktonic food supply toward the surface at dusk, and descend again at daybreak.

Emerald shiners move inshore in the spring and fall (Scott and Crossman 1973) and stay offshore during summer. This seasonal distribution pattern was observed for Pigeon Lake emerald shiners during 1977-1979. For a more detailed description see Jude et al. (1978, 1979a, 1980).

During 1977-1979 the distribution of emerald shiner larvae was difficult to describe because of problems in distinguishing emerald shiner larvae from other cyprinids. Due to increased expertise in larval fish identification, emerald shiner larval distribution during 1979 can be discussed. Station S (Lake Michigan influenced) was the preferred habitat for Pigeon Lake emerald shiner larvae. Densities as high as 290/1000 m^3 were observed at this station in early August. The occasional occurrence of emerald shiner larvae at station X (undisturbed Pigeon Lake) indicated that this species may spawn in areas of Pigeon Lake not influenced by Lake Michigan.

Golden Shiner

Golden shiners live in clear, weedy, quiet water with extensive shallow areas. This fish swims actively in schools, covering large areas just off the bottom (Scott and Crossman 1973). They feed at mid-water or the surface and help control mosquitoes to some extent (Becker 1976).

During 1977 sampling began in June and 2615 golden shiners were caught. The size range was 23-170 mm, with most between 40 and 100 mm. Most of the catch (92%) was seined at Pigeon River-influenced beach station T, with the remainder being seined at stations S (Lake Michigan influenced) and V (undisturbed Pigeon Lake).

In 1978 220 golden shiners were caught in Pigeon Lake; 96% were caught in April and May. This species spawns between late May and early June in Pigeon Lake (Jude et al. 1979a) so the large catches during April and May indicated a concentration at station V due to spawning activity. Most fish were adults (50-100 mm) with moderate or well developed gonads. Pigeon River-influenced station T was not sampled in 1978 or 1979. Only a few YOY golden shiners were caught at Lake Michigan-influenced station S in 1978; thus station V (undisturbed Pigeon Lake) was the preferred habitat of this species in 1978.

Neither YOY nor adult golden shiners were caught in large numbers in 1979; only 20 were caught. Jude et al. (1980) theorized that golden shiners may have been displaced by yellow perch at station V in 1979, since extensive perch spawning occurred there in 1979. Golden shiners may have dispersed into other areas of Pigeon Lake to spawn and were not sampled. Even if golden shiners spawned successfully at station V in 1979, extremely abundant yellow perch larvae and YOY would have preyed upon larval and YOY golden shiners or competed

with them for food. Thus, absence of YOY golden shiners from our samples could be expected.

Although adult golden shiners were abundant in Pigeon Lake in 1977 and 1978, few larvae were collected, which may be related to problems in identifying cyprinid larvae during those years. All identified golden shiner larvae collected in 1977 and 1978 were collected during June and July at beach station S (Lake Michigan influenced) and T (Pigeon River influenced). Larvae caught in June at station T ranged in length from 7.5 to 20.0 mm and were taken in densities from 85 to 690/1000 m^3. During late July larvae from 4 to 16 mm in length with densities up to 807/1000 m^3 were caught at Lake Michigan-influenced station S. Only one golden shiner larva (5.8 mm) was collected in 1979 at undisturbed Pigeon Lake station X. The small size of this larva suggests that spawning occurred in late April-early May during 1979. Although station T (Pigeon River influenced) was not sampled in 1978-1979, visual observations indicated that small golden shiner aggregations (15-30 individuals) were common near emergent vegetation in this area.

Common Shiner

Although principally a stream fish through most of its range, the common shiner does occur in the shore waters of clearwater lakes (Scott and Crossman 1973). Because of its preference for streams, the common shiner is apparently rare in Pigeon Lake, as only six were collected during 1977-1979. It is evident that this species occurs only sporadically in Pigeon Lake and possibly migrates from the upper reaches of the Pigeon River.

Sand Shiner

The sand shiner prefers sandy, sparsely vegetated shallow areas of lakes and large rivers; it is found in streams close to Lake Michigan (Becker 1976). Sand shiners were caught in Pigeon Lake in 1978 and 1979. During 1978 two immature sand shiners were seined at Lake Michigan-influenced station S, one each in September and October. In 1979 two immatures (38 and 40 mm), two adult males (58 and 68 mm), and one adult female (65 mm) were seined at station S in May. Thirteen adults were seined at station V (undisturbed Pigeon Lake) in June. Gonad data suggested that spawning may have occurred in June or early July in Pigeon Lake. Two of the female sand shiners caught in June had well developed ovaries. It appears some sand shiners move into the beach zone in Pigeon Lake in the spring, spawn there in June or July, and move into the deeper water of Pigeon Lake in the summer with some returning to the beach zone in the fall.

Fathead Minnow

Although fathead minnows are reported by Becker (1976) to be common in the Lake Michigan watershed and to prefer a wide variety of lentic and lotic habitats throughout their range (Scott and Crossman 1973), their occurrence in Pigeon Lake appears to be incidental. None were caught in 1977, 3 were caught in 1978 and 15 in 1979 (30-70 mm).

Lake Chubsucker

The lake chubsucker is a common species in the southern half of lower Michigan where it occurs in lakes, ponds, rivers, and quieter streams (Becker 1976). Although this species is of little value as a commercial or sport fish, it serves as forage for northern pike and grass pickerel in Pigeon Lake. A small resident population of lake chubsuckers exists in Pigeon Lake.

The lake chubsucker usually inhabits areas of lakes and rivers with submerged aquatic vegetation and substrates of sand or fine gravel (Trautman 1957). Such areas are common to the eastern portion of Pigeon Lake. During 1977, 45 of 46 chubsuckers were caught in the eastern Pigeon River-influenced portion of Pigeon Lake; only 1 was caught in Pigeon Lake in 1978 and none in 1979. The eastern part of Pigeon Lake was not sampled in 1978 and 1979. Size range of the lake chubsuckers caught in 1977 and 1978 was 50-210 mm. Many individuals were observed while electrofishing in 1978.

Brook Silversides

Brook silversides are commonly found within the southern two-thirds of the Lake Michigan basin (Becker 1976), although near Port Sheldon they approach the northern limit of their range. Brook silversides are small forage fishes having a 1-yr life cycle (Hubbs 1921). Spawning usually occurs during early summer when water temperatures reach 20 to 22.7 C (Hubbs 1921, Becker 1976). During our study 158, 80, and 87 silversides were caught during the period 1977-1979. Most were caught in the central and eastern portions of Pigeon Lake; few were caught in the Lake Michigan-influenced portion of Pigeon Lake. Silversides caught ranged in size from 28 to 102 mm and 0.1 to 4.19 g. Average YOY growth rates from modal lengths were estimated to be 0.81 mm/day from July through September in Pigeon Lake. A higher rate (1.07 mm/day) was estimated for the period July through August.

Lake Trout

One lake trout (640 mm) was gillnetted at openwater station M in June 1977, while during October 1978 lake trout 440-880 mm were also gillnetted there. No lake trout were collected in Pigeon Lake during 1979; deletion of gillnetting station M is the most likely reason. Lake trout are not permanent residents of Pigeon Lake, but occaisionally enter Pigeon Lake from Lake Michigan.

Brown Trout

One brown trout (120 mm) was seined in May 1979 from Pigeon Lake. This fish most likely entered the lake from Lake Michigan. These fish are rare in Pigeon Lake proper, though some are thought to inhabit Pigeon River.

Coho Salmon

One coho salmon (410 mm) was caught in October 1977 in Pigeon Lake. During 1978 18 juvenile coho salmon 74-165 mm were seined during May at undisturbed Pigeon Lake beach station V. These fish were most likely just planted in the Grand or Kalamazoo rivers. Coho are planted in the spring at

about 102-152 mm (M. Patriarche, personal communication, Institute for Fisheries Research, MDNR, Ann Arbor, Mich.). During 1979 three coho were seined in Pigeon Lake. All were juvenile fish 120-130 mm and probably newly planted fish.

Although the upper reaches of the Pigeon River have not been examined for salmon fry, electrofishing revealed the presence of adult salmon there during spawning season. Salmon are not planted in the Pigeon River, but enter it from Lake Michigan. It is possible that some natural reproduction could therefore occur in the Pigeon River.

Chinook Salmon

Although no chinook salmon were collected in regular monthly sampling in Pigeon Lake during 1977, a large adult was taken while electrofishing opposite station T (Pigeon River influenced) during October. Three chinook were caught in Pigeon Lake in 1978; a 690-mm adult was caught in September and two juvenile fish were seined in April and May. During 1979 12 chinook between 80 and 335 mm were seined in Pigeon Lake; 11 were small 80 to 130-mm fish seined at station S (Lake Michigan influenced) during May (2), June (3) and July (6). These were probably newly planted fish which entered Pigeon Lake via Lake Michigan. Although it has not been documented, limited spawning by chinook salmon may occur in the Pigeon River (Jude et al. 1978).

Rainbow Trout

The Michigan Department of Natural Resources (MDNR) released between 10,000 and 40,000 rainbow trout in Pigeon Lake in 1973, 1976, and 1977. These fish undoubtedly moved out into Lake Michigan soon after planting. Gonads of a 581-mm male were found in ripe-running condition in Pigeon Lake in November 1977, indicating that some planted fish returned to spawn in the Pigeon River. In 1978 six rainbows were caught in Pigeon Lake; five were immature and ranged in size from 123 to 175 mm. They were seined in June (3) and July (2) at beach station S (Lake Michigan influenced). Presumably, these fish were planted, but rainbows can reproduce naturally in the upper regions of Pigeon Creek (R.S. Lincoln, personal communication, MDNR, Grand Rapids, Mich.). One adult male (600 mm) was gillnetted at station M (influenced by Lake Michigan) in October. No rainbow trout were caught in Pigeon Lake during 1979, although visual observations documented their presence in the Pigeon River during March and April 1980.

Yellow Bullhead

The yellow bullhead is widely distributed throughout the Lake Michigan basin (Becker 1976). It usually occurs in slow-moving streams, shallow bays of lakes, and in ponds with abundant aquatic vegetation (Trautman 1957). In 1977, 35 yellow bullheads were caught in Pigeon Lake. They appeared to be less abundant than their interspecific competitors, either the brown bullhead, (of which 120 were caught in 1977); or black bullheads (17 caught in 1977).

Eighteen of the yellow bullheads caught were 19-61-mm YOY. All were caught by seine; 11 at Pigeon Lake undisturbed station V, 6 at Pigeon River-influenced station T, and 1 at Lake Michigan-influenced station S. Of the remaining 17 fish which ranged from 94 to 421 mm, 11 were gillnetted at openwater station M (influenced by Lake Michigan) and 6 were seined at the

three Pigeon Lake beach stations (S, T, and V). These data indicated that YOY bullheads avoided areas influenced by Lake Michigan, while larger individuals occupy several types of habitat in Pigeon Lake. With the exception of one fish, all were caught at night. Gonad data suggested that yellow bullheads spawned in May or early June in Pigeon Lake during 1977.

Due to deletion of stations T (Pigeon River influenced) and Y (undisturbed Pigeon Lake) from our sampling in 1978 and 1979, catches of yellow bullheads declined considerably after 1977. During 1978, seven yellow bullheads were caught in Pigeon Lake. All were seined at beach station V (Pigeon Lake undisturbed); three fish (45, 53, and 75 mm) were caught in April at 12.5 C. The other four yellow bullheads (120-380 mm) were caught in June at a water temperature of 18.0 C. Only one yellow bullhead, a 250-mm female, was caught during 1979. It was seined in August at beach station V.

Brown Bullhead

The brown bullhead was the most common ictalurid species collected in Pigeon Lake during 1977-1979. It is dispersed throughout the Lake Michigan basin (Becker 1976) and generally inhabits weedy and deeper waters of lakes and sluggish streams (Hubbs and Lagler 1958).

During 1977, 120 brown bullheads were collected in Pigeon Lake; 82 were caught at Pigeon River-influenced station T, 23 at station Y (undisturbed Pigeon Lake), 9 at openwater station M (influenced by Lake Michigan) and 6 at beach station V (undisturbed Pigeon Lake). Located in areas of soft bottom with abundant aquatic macrophytes near the Pigeon River, stations T and Y were the most preferred habitats for brown bullheads.

Because stations T and Y were deleted from the 1978 and 1979 sampling series, only six and nine brown bullheads respectively were caught during those years. The majority of the brown bullheads were caught at night, which is in agreement with the known nocturnal habits of this species. Adult brown bullheads ranged in size from 95 to 365 mm while YOY ranged from 23 to 79 mm. Jude et al. (1978) reported that brown bullheads spawn during May and June in Pigeon Lake. Water temperatures at time of capture ranged between 8.0 and 23.4 C. YOY were collected mostly at higher temperatures (16-23.4 C), while adults were caught at water temperatures between 8.0 and 12.0 C. Food in the stomach of many fish caught at temperatures between 8.0 and 12.0 C indicated they were actively feeding at this temperature range.

Brown bullheads appeared to have successfully dominated the other bullheads in Pigeon Lake (black and yellow bullheads), probably because they are best suited for this type of habitat. Trautman (1957) indicated that the black bullhead was unable to invade cool, deep waters inhabited by the brown bullhead, and abundance of yellow bullheads in an area may be limited by the presence of the other two species.

Black Bullhead

The black bullhead is widespread in the freshwaters of North America (Scott and Crossman 1973). In Michigan, it is commonly found in lakes, warm streams, and rivers. During 1977, 17 black bullheads were caught in Pigeon Lake. Presence of 11 YOY (49-91 mm) suggested that Pigeon Lake was utilized as a nursery area. Adults caught in 1977 ranged in size from 289 to 321 mm. Only

three black bullheads were caught during 1978-1979. Deletion of station T (Pigeon River influenced) and Y (Pigeon Lake undisturbed), where 12 of 17 specimens were caught in 1977, is the most likely reason for reduced catch in 1978-1979. Jude et al. (1979a) reported that black bullheads spawned during June and July in Pigeon Lake during 1978. Black bullheads are usually not present in areas where brown or yellow bullheads live (Scott and Crossman 1973). This may help explain their low abundance in Pigeon Lake, since large numbers of brown bullheads inhabit the eastern portion.

Tadpole Madtom

The tadpole madtom is distributed throughout the Lake Michigan basin except for the extreme northern portions (Becker 1976). Tadpole madtoms inhabit slow-moving streams and shallow areas of lakes with soft muddy bottoms and abundant aquatic vegetation (Scott and Crossman 1973). During 1977, 55 tadpole madtoms were seined from Pigeon Lake. Beach stations T (influenced by Pigeon River) and V (undisturbed Pigeon Lake) represent the typical habitat of this species; 36 and 17 fish respectively were caught at these two stations. Adult fish caught in 1977 ranged in size from 74 to 89 mm; yearlings caught in June and July were 40-68 mm and YOY caught in September-November were 29-58 mm. During 1978 and 1979, 17 and 18 madtoms were seined in Pigeon Lake. Deletion of beach station T from 1978-1979 sampling is most likely responsible for the decline in catch from 1977 levels. Station V (undisturbed Pigeon Lake) was preferred by madtoms over station S (Lake Michigan influenced) during the 1977-1979 study period. Jude et al. (1980) reported that tadpole madtoms spawned during May or June in Pigeon Lake; most were caught when water temperatures were 10-19 C.

Channel Catfish

The channel catfish is native to streams and lakes of eastern United States and southern Canada (Scott and Crossman 1973). Jude et al. (1978) documented the presence of channel catfish in Lake Michigan near Port Sheldon. The only channel catfish caught in Pigeon Lake during the study period (1977-1979) most likely moved into the lake from Lake Michigan. One YOY (58 mm) was seined at Lake Michigan-influenced station S in November 1977. The habitat preference of this species precludes its abundance in Pigeon Lake.

Flathead Catfish

Only one flathead catfish was collected in our 3 yr of sampling effort; this was a 375-mm specimen found in an impingement sample in April 1979. Becker (1976) reported that this species inhabits the Grand River and Black River basins; these rivers empty into Lake Michigan at points within a 20-km radius of Pigeon Lake. This individual may have been a stray from one of these two rivers and having entered Pigeon Lake was later impinged.

Rainbow Smelt

Rainbow smelt are not residents of Pigeon Lake. No major smelt run was observed in Pigeon Lake or Pigeon River, but a few smelt may utilize this tributary water as a spawning ground. Only seven smelt, including one 28-mm YOY caught at Pigeon River-influenced beach station T, five yearlings and one adult, were caught in Pigeon Lake in 1977. During April 1978 three smelt were caught in Pigeon Lake. Of these, two were females with ripe-running and well

developed gonads; both were caught in bottom gill nets at 6-m station M (influenced by Lake Michigan). The third was a 60-mm yearling seined at beach station S (Lake Michigan influenced). In May 1978 six 43-79-mm smelt were collected in Pigeon Lake, three at beach station S and three at beach station V (undisturbed Pigeon Lake). The only other smelt caught in 1978 was a YOY (40 mm) seined at station S in August. In 1979 smelt were caught in Pigeon Lake in May, August, and October. In May three yearlings 51, 61 and 65 mm were seined at beach station S at a water temperature of 12.6 C. A 61-mm yearling was seined at station V when water temperature was 14.9 C.

During August five YOY smelt 25-29 mm were seined at station S when water temperature was 12.8 C, while day seine hauls in October collected one 50-mm YOY. Since smelt larvae were scarce in Pigeon Lake during 1977-1979, yearlings and YOY smelt caught had probably migrated into Pigeon Lake from Lake Michigan.

Bowfin

The bowfin is the only surviving member of an ancient fish family that has long been extinct (Hubbs and Lagler 1958). Bowfins in North America inhabit swampy, vegetated bays of warm lakes and rivers (Scott and Crossman 1973). In Michigan, the northern limit of their distribution reaches the southern portion of the upper peninsula (Becker 1976).

During 1977, 70 bowfins were collected in Pigeon Lake. Adult fish ranged in size from 317 to 761 mm. Due to a reduction in sampling effort in 1978 and 1979 (stations T, influenced by Pigeon River, and undisturbed Pigeon Lake station Y were deleted), catch of bowfins was reduced to 13 and 3 individuals during those years. Bowfins were caught over a broad range of water temperatures (2.4-26.9 C) with most catches occurring between 8.0 and 19.0 C. Station Y and other areas not disturbed by the inflow of Lake Michigan water were preferred habitats during warmer months. Most bowfins collected had empty stomachs; stomach contents of fish which had eaten included alewives, gizzard shad, spottail shiners, and other animal remains. Scott and Crossman (1973) reported that bowfins prey on all kinds of fish and may become a serious predator and competitor of sport fishes. Since bowfins are not a popular game fish, angler mortality is low. Thus, we believe their population has remained high in Pigeon Lake which electrofishing confirmed.

Bowfins spawn in April in Illinois, June in Ontario, and from April to July over its entire range (Carlander 1969). The male builds the nest in shallow, vegetated areas of lakes and streams and guards the young until they reach about 102 mm in length (Scott and Crossman 1973). Our gonad data (Jude et al. 1978) indicated that most spawning in Pigeon Lake occurred from May to July. Several bowfin larvae (11-25 mm) were caught on 4 June 1979, indicating that spawning does occur in May.

Burbot

The burbot is a common species in Lake Michigan (Becker 1976). In central and southern Canada, the burbot is usually a resident of deep waters of lakes, whereas in northern Canada, it is also present in large cool rivers (Scott and Crossman 1973). McCrimmon and Devitt (1954) reported movement of burbot into rivers beneath the ice, but they believe the primary spawning ground for this species is open lake habitat.

One male (401 mm) with well devloped gonads was caught in December 1977 in Pigeon Lake. Supplementary gillnet sampling in Pigeon Lake and Pigeon River during December and February indicated some burbot do move into these areas in winter months. Spawning undoubtedly occurred because larval burbot were observed in April and May entrainment samples (Jude et al. 1980). This species does not inhabit Pigeon Lake during the entire year; it comes into Pigeon Lake from Lake Michigan only during colder months.

Grass Pickerel

A close relative of the northern pike, the grass pickerel, is a common resident of the quiet weedy waters of the lower half of the Lake Michigan drainage basin (Becker 1976). This species is a smaller member of the pike family with a maximum size in the United States of 381 mm, 397 g (Trautman 1957). Due to its size, this fish has little sport or commercial value. They are known to hybridize in nature with northern pike, producing infertile offspring (Scott and Crossman 1973).

Spawning usually occurs during April in Ontario (Crossman 1962), but there is evidence of fall spawning (Scott and Crossman 1973). Gonad data (Jude et al. 1978) indicate that spring spawning is most likely in Pigeon Lake. Specimens ranged in size from 70 to 290 mm.

The grass pickerel is a common inhabitant of Pigeon Lake. There is a preference for shallow nearshore habitat, as most were seined in areas of gradual slope (Jude et al. 1978). Catch temperatures ranged from 8.0 to 26.5 C. Preferred temperature has been reported to be 25.5 C (Crossman 1962), indicating that this species is tolerant of relatively high temperatures.

Grass pickerel in Pigeon Lake function ecologically as both predator and prey. Grass pickerel have been found in the stomachs of northern pike. In turn, grass pickerel stomachs have contained yellow perch, lake chubsuckers, bluntnose minnows, and golden shiners. The habitat as well as food supply in Pigeon Lake are highly conducive to the survival and propagation of this species.

Tiger Muskellunge

A tiger muskellunge is the result of hybridization of the northern pike with the muskellunge. Although not common, this species has been observed twice while electrofishing, and one specimen was seined in Pigeon Lake.

Ninespine Stickleback

Although common in Lake Michigan, ninespine sticklebacks are not abundant in Pigeon Lake. The debris-covered bottom and protected areas of Pigeon Lake seem like optimal habitat for this species. Spawning in Pigeon Lake was evidenced by the occurrence of larvae during June 1977 and April-May 1978. In situations where they are abundant, ninespine sticklebacks are important forage for other game species (Scott and Crossman 1973). Jude et al. (1978) found this species in stomachs of yellow perch.

Walleye

No walleyes were caught in Pigeon Lake during 3 yr of study; however, one was sighted in the lake during electrofishing operations in 1977. Seven walleyes (122-216 mm in length) were seined in Lake Michigan in 1978; they were determined to be YOY using the scale method of aging. Although walleyes are not abundant in southeastern Lake Michigan, large numbers of walleyes are planted in the Muskegon River system and in Lake Macatawa (R. Lincoln, personal communication, MDNR, Grand Rapids, Mich.). Walleyes caught and sighted in the study area are probably the stocked fish from the Lake Macatawa, Grand River, or Muskegon River plants, or they may be the result of natural reproduction of stocked fish.

At lengths over 76 mm, walleyes feed mainly on fish, including trout-perch and yellow perch (Becker 1976); Wagner (1972) reported that in Lake Michigan walleyes feed heavily on alewives and smelt. Northern pike is an important predator of walleye and may also be a major competitor (Scott and Crossman 1973). Pigeon Lake offers substantial populations of forage fish but also contains a stable northern pike population. Due to a large demand for and a limited supply of walleyes to stock, Pigeon Lake has not received plants of walleye (R. Lincoln, personal communication, MDNR, Grand Rapids, Mich.).

Walleyes are a highly desirable species as a sport fish and as a commercial fish. In Lake Michigan the commercial fishery is centered in Green Bay (Becker 1976).

Logperch

Three logperch were caught in our field sampling during this 3-yr study; all three individuals (40-46 mm in length) were seined during the day at station V (undisturbed Pigeon Lake) in July 1979. These demersal fish were observed by SCUBA divers in the riprap of the jetties at the mouth of Pigeon Lake during 1978 and 1979. In 1978 a larval logperch was collected in Lake Michigan at station E (12 m, south transect).

Logperch inhabit sand, gravel, or rocky beaches of lakes. The low catches of logperch in the area reflect the low abundance of logperch in Pigeon Lake.

Iowa Darter

Iowa darters inhabit clear, standing, or slowly moving waters of lakes or rivers which have rooted aquatic vegetation and a bottom of organic debris, sand, peat, or a composite of these (Scott and Crossman 1973). This species is locally common to uncommon in the Lake Michigan basin (Becker 1976). Only one specimen was collected during the 3 yr of the study; this was a 47-mm individual (0.8 g) seined at Pigeon Lake station S (Lake Michigan influenced) in April 1978. This species appears to be rare in Pigeon Lake.

Blackside Darter

The blackside darter is a stream species preferring quiet, clear pools with bottoms of sand and gravel, but is tolerant of turbid waters (Scott and Crossman 1973). No blackside darters were collected in 1977; one immature (29 mm) was seined at station S (Lake Michigan-influenced beach station) in July

1978. Two individuals were seined during 1979; one immature (51 mm, 1.0 g) at station V (undisturbed Pigeon Lake) in July and an adult male (57 mm, 1.9 g) at station S in September. Fish caught in Pigeon Lake may be strays from the Pigeon River; SCUBA divers observed blackside darters in considerable numbers in the Pigeon River within 1 km of Pigeon Lake beach station T (influenced by Pigeon River) in September 1978. Supplementary seining during November 1979 at a Pigeon River site over 4 km from station T showed the blackside darter to be common there. Individuals collected ranged from 25 to 80 mm.

Trout-perch

Trout-perch was a major species in Lake Michigan catches but was not found in Pigeon Lake in high numbers. In 1977 only four trout-perch were caught in Pigeon Lake; all were caught in a bottom gill net at station M (Lake Michigan influenced). These adults (110-120 mm) were caught in November and December. Fifteen trout-perch were caught in Pigeon Lake during 1978, including nine adults (80-100 mm) and six yearlings (30-60 mm). During May 1978, seven adults were seined at beach station V (undisturbed Pigeon Lake) and two were caught in a bottom gill net at station M (Lake Michigan influenced), one in November and one in December. One yearling was caught in April, two in May, and one in September at station S; two yearlings were caught at station V in May. Thirty trout-perch were collected in Pigeon Lake during 1979; all were yearlings caught in seine hauls at station S (Lake Michigan influenced). During 1979, 1 was caught in July, 7 in September, and 22 in October. During the 3-yr study all but two trout-perch collected in Pigeon Lake were caught at night. Trout-perch may be moving into Pigeon Lake from Lake Michigan to feed. Data from 1977 to 1979 show no indication of trout-perch spawning in Pigeon Lake.

Trout-perch are small, bottom-dwelling fish which feed on a variety of aquatic insect nymphs, amphipods, copepods and several other crustaceans. They probably move into shallow areas of lakes at night to feed (Scott and Crossman 1973). Trout-perch are not known to be an important forage species in various areas in southeastern Lake Michigan (Jude et al. 1979a, 1979b; House and Wells 1973). During our study from 1977 through 1979 trout-perch seldom occurred in the stomachs of predatory fish.

Bigmouth Shiner

The bigmouth shiner is common in small to medium-sized streams preferring streams with sand bottoms and some gravel (Becker 1976). Only one bigmouth shiner was caught during our field sampling efforts, a 63-mm individual seined at station V (undisturbed Pigeon Lake) in June 1977. This species is probably uncommon in Pigeon Lake.

Creek Chub

The creek chub seems to prefer small, clear streams but does inhabit shore waters of small lakes (Scott and Crossman 1973). The three individuals caught by our standard series sampling efforts were seined at station V (undisturbed Pigeon Lake) in July 1978 during the day. This species is uncommon in Pigeon Lake.

Blacknose Shiner

Only one blacknose shiner was caught, a 63-mm specimen seined at station V (undisturbed Pigeon Lake) in June 1977. This species is reported to range from uncommon to common in the Lake Michigan basin and prefers clear, weedy lakes and streams with mud, sand, or gravel bottom (Becker 1976). The blacknose shiner is a rare species in Pigeon Lake.

Longnose Dace

The longnose dace is often associated with gravel and boulder bottoms of fast-flowing streams, but also occurs in inshore waters of lakes (Scott and Crossman 1973). In this study only one specimen was caught in Pigeon Lake; an immature (38 mm) seined at station S (Lake Michigan influenced) at night in September 1977. This species is uncommon in Pigeon Lake and in Lake Michigan in the vicinity of the J.H. Campbell Plant (only three longnose dace were caught by our sampling in Lake Michigan; all were caught during 1977).

Goldfish

Goldfish prefer shallow, heavily vegetated, warm-water areas, and in the Great Lakes region are abundant in Lake Erie, Lake St. Clair, and the Detroit River (Scott and Crossman 1973). They feed on a wide variety of plants and animals including larval and adult aquatic insects, molluscs, crustaceans, and aquatic vegetation. Goldfish up to 1 or 2 kg are fed upon by piscivorous fish.

A few goldfish were collected every year (1977-1979) from Pigeon Lake. Two were seined in Pigeon Lake in 1977, one in 1978, and two in 1979. These five fish included three YOY goldfish (20-50 mm) and two adults (285 mm, 297 mm). A few goldfish were also seen during 1977-1979 electroshocking activities on Pigeon Lake. Most goldfish observed were "wild" olive-green in color; at least one gold-colored individual was sighted. The few larval goldfish identified during this study were collected exclusively in entrainment samples in late May 1978. These fish ranged from 5.5 to 6.0 mm in length and may just have been a few days old at capture, since hatching lengths have been reported to fall in the 4.0- to 4.5-mm range (for goldfish from the Delaware River system) (Wang and Kernehan 1979). Goldfish probably spawned in the intake canal beginning in May (Jude et al. 1979a).

Carp

Carp prefer an environment with a shallow, marshy area and dense aquatic vegetation in which to feed and spawn, as well as a deepwater area for overwintering. The study area, which includes the inshore area of Lake Michigan in the J.H. Campbell Plant vicinity, Pigeon Lake, and the intake canal, offers this combination.

A few carp were caught in standard series sampling in Pigeon Lake during 1977 and 1978. These carp were caught throughout Pigeon Lake from the river-influenced section (station T) to the Lake Michigan-influenced area (station M). Carp have also been observed in Pigeon Lake during electroshocking activities. They were sighted in the intake canal on several occasions from 1977 to 1980. Carp have also been caught in Lake Michigan.

Larval data indicate extensive carp spawning in the intake canal, particularly during May. The preferred spawning sites in Pigeon Lake are the heavily vegetated, shallow areas like station T (influenced by Pigeon River) and station V (undisturbed Pigeon Lake). During supplementary sampling activity carp larvae were caught in a larval seine fished in heavily weeded areas on the south side of Pigeon Lake. Larvae data for 1979 indicate a peak spawning of carp in Pigeon Lake during July. Spawning appears to conclude in August.

In August 1978 five immature carp and one carp in poor condition were caught in Pigeon Lake; these fish ranged in length from 50 to 140 mm. In July 1977 one 32-mm immature was caught in Pigeon Lake. All these immature fish were probably YOY, showing Pigeon Lake is quite suitable for carp growth. The 16 adult carp caught in Pigeon Lake during 1977 and 1978 (none were caught in Pigeon Lake in 1979) ranged in length from 200 to 770 mm.

Carp usually lay their adhesive eggs on aquatic vegetation in shallow water less than 1.2 m deep (Jester 1974). Carp are omnivorous, feeding on a variety of plants and animals including aquatic macrophytes and algae as well as aquatic insects, crustaceans, annelids, and molluscs. Young carp probably fall prey to northern pike and bass, although no carp have been found in stomachs of piscivorous fish caught in Pigeon Lake. Once carp attain a weight of 1 to 2 kg, their only predator is man.

Banded Killifish

Banded killifish prefer the quiet waters of lakes and ponds and are usually found in small schools over sand, gravel, or detritus bottom areas with patches of submerged macrophytes (Scott and Crossman 1973). This species is often found in shallow waters associated with rushes (Hubbs and Lagler 1958). Banded killifish spawn in May, and feed on a variety of organisms including chironomid larvae, ostracods, cladocerans, copepods, amphipods, and flying insects. It is probably one of the few species in Pigeon Lake to feed substantially on ostracods.

Numbers of banded killifish collected by standard series sampling in Pigeon Lake varied considerably during the study years 1977 to 1979. Only two banded killifish were captured in 1977; both were seined at station V (undisturbed Pigeon Lake) in November (Jude et al. 1979a). However, in 1978 51 individuals (30-50 mm) were seined in Pigeon Lake; 3 at station S (Lake Michigan influenced) and 48 at station V (undisturbed Pigeon Lake). In 1979 nine banded killifish (36-52 mm) were captured; all were seined in Pigeon Lake. Four were seined at station V and five were seined at station S during June through October 1979. This species apparently prefers warmer temperatures; all were caught at water temperatures between 12 and 20 C. Killifish caught corresponded to age-groups-0 and -1 fish according to Scott and Crossman (1973); almost all killifish caught during the study fell in these age-groups.

The higher catch at station V compared to station S indicates a preference for denser aquatic vegetation and more extensive areas of shallow water. The banded killifish appears to range from uncommon to common in Pigeon Lake. Although it was not found in the stomachs of other fish, it is undoubtedly preyed upon by some game fish in the lake.

Central Mudminnow

The central mudminnow inhabits small creeks and isolated ponds (Scott and Crossman 1973). One female with ripe-running ovaries (60 mm, 2.5 g) was caught in Pigeon Lake in May 1978. This species is rare in Pigeon Lake, but supplementary seining during November 1979 showed it to be common in the small creek tributaries of the Pigeon River within 10 km of beach station T (Pigeon River influenced).

Pirate Perch

The pirate perch is far from abundant in the Great Lakes region (Hubbs and Lagler 1958). It is an inhabitant mainly of creeks and is sometimes found in larger rivers and lakes. Only one pirate perch (72-mm male) was caught in Pigeon Lake by our sampling efforts; it was seined in October 1977 at beach station T (influenced by Pigeon River). Several pirate perch were observed near station T and open water station Y (Pigeon River influenced) during electrofishing operations in both 1977 and 1978. One pirate perch was collected at a Pigeon River site over 4 km from station T during supplementary seining in November 1979. This species is uncommon in Pigeon Lake and its population in the lake appears to be centered in the river-influenced area.

Slimy Sculpin

The slimy sculpin is a demersal species common in Lake Michigan, where it is found mainly in the nearshore area to about 90 m (Deason 1939). Wells (1968) believes that the bulk of the slimy sculpin population in Lake Michigan does not inhabit depths less than 18 m at any time during the year. In our study area, slimy sculpins are chiefly a species of Lake Michigan, but may enter Pigeon Lake. A few slimy sculpins were seined in the Lake Michigan-influenced beach area of Pigeon Lake; all of these fish were caught during 1977. Slimy sculpins prefer cooler temperatures and were rarely caught at temperatures exceeding 15 C. Brown and lake trout were found to consume many slimy sculpins in Lake Michigan.

Mottled Sculpin

The mottled sculpin is a common inhabitant of Lake Michigan where it occupies the inshore areas and mouths of shallow tributaries (Deason 1939). In Pigeon Lake it appears to range from uncommon to common, and is found mainly in the Lake Michigan-influenced section of the lake. In 1977 and 1978 only a few were collected. In 1979 however, 72 (20 to 90 mm in length) were seined in Pigeon Lake and almost all were collected during September through November. There may be a movement of mottled sculpins to the shallow, sandy, sparsely vegetated areas of Pigeon Lake during autumn. Individuals of this species appear to move into shallow water at night and spend days in deeper water (Jude et al. 1980). A few mottled sculpins have been caught at station V (undisturbed Pigeon Lake) and in Lake Michigan at a depth of 12 m.

White Sucker

The white sucker inhabits both lakes and streams (Scott and Crossman 1973). In Lake Michigan it is known to move into tributary streams to spawn; such spawning may occur from late March through May for southeastern Lake

Michigan (Jude et al. 1975, 1979b). The white sucker is a very common species in Lake Michigan waters near the J. H. Campbell Plant, but is not often collected from Pigeon Lake.

In our study 18 adult white suckers (260-580 mm) were collected from Pigeon Lake from July through December 1977. During 1978, six white suckers were caught; these included four adults (410-740 mm) caught from May through August in bottom gill nets set at station M (Lake Michigan influenced), one 70-mm immature seined at beach station S (Lake Michigan influenced) in April, and one 90-mm immature seined at station V (undisturbed Pigeon Lake) in May. Twenty-two white suckers (40-380 mm) were caught in Pigeon Lake in 1979; all were seined at station S between May and September. Of these 22 suckers, 16 individuals (40-70 mm) were caught in July. These 16 fish were either YOY or yearlings; however, Scott and Crossman (1973) reported that growth for young white suckers varies considerably from lake to lake, so age composition of these young suckers is not certain.

Sucker larvae were collected in Pigeon Lake and were entrained by the J. H. Campbell Plant; these larvae were possibly the result of spawning activity in Pigeon Lake or more likely the Pigeon River. Two sucker larvae were collected at station S (Lake Michigan influenced) during May 1978, and 29 sucker larvae were counted in entrainment samples for May and June 1978. Most larvae were relatively small (5.0 to 9.1 mm) and were probably white suckers, while three were over 10 mm and were probably longnose suckers (Jude et al. 1980). Longnose suckers spawn earlier than white suckers and would likely be larger at time of collection (Scott and Crossman 1973). In 1979 one sucker larva (22 mm) was collected at station S in May. Eleven suckers were collected in entrainment samples during April and May. Again, two size groups appeared. For May 1979 entrainment, the three smaller larvae (7.5-8.1 mm) were believed to be white suckers and the four larger larvae (14.0-20.0 mm) were probably longnose suckers. These data imply that white sucker spawning occurring in April and May in the vicinity of the Campbell Plant.

During February 1980 an adult white sucker was caught in a supplementary bottom gill net set near the entrance of Pigeon River into Pigeon Lake. SCUBA divers observed white sucker YOY in the Pigeon River within 1 km of Pigeon Lake station T (Pigeon River influenced) in 1978. However, the Pigeon River (or Pigeon Lake) does not appear to be a site of major spawning runs for white sucker since relatively low numbers were caught in Pigeon Lake during the 3-yr study. Pigeon Lake serves as a nursery area for some white suckers.

Longnose Sucker

The longnose sucker, like the white sucker, is common in Lake Michigan waters near the J. H. Campbell Plant, but is not common in Pigeon Lake. No YOY or adult longnose suckers were caught in Pigeon Lake in 1977 or 1978 however, 13 individuals were caught in Pigeon Lake in 1979. These suckers (40-70 mm) were all seined at station S (Lake Michigan influenced) in July and were probably all YOY (Jude et al. 1980). Sucker larvae believed to be longnose suckers were collected during May and June 1978 and late April and May 1979. These larvae were chiefly found in entrainment samples, but a few were caught at beach station S.

Some longnose suckers apparently enter Pigeon Lake (and most likely continue up the Pigeon River) from Lake Michigan to spawn in spring (April and

May). One adult longnose sucker was captured in mid-March 1980 in a bottom gill net (supplementary sampling) set in the channel connecting Lake Michigan and Pigeon Lake. Longnose suckers probably spawn slightly before white suckers (perhaps some longnose sucker spawning occurs in mid-March in the Pigeon River) (Jude et al. 1980). There is no evidence for a major spawning run of longnose suckers in the Pigeon Lake-Pigeon River system. Pigeon Lake however, does apparently serve as a nursery area for longnose suckers.

Shorthead Redhorse

Shorthead redhorses occurred sporadically in the vicinity of the Campbell Plant. Only three specimens were collected in Pigeon Lake from 1977 to 1979; these were three adults (420-545 mm) gillnetted at station M (Lake Michigan influenced) in June (one fish) and September (two fish) in 1978. These fish usually migrate from large bodies of water into small rivers and streams (Scott and Crossman 1973) to spawn in late April-late July. The individual caught in June may have been headed for the Pigeon River to spawn.

Golden Redhorse

The golden redhorse is probably better adapted for rivers than for lakes (Scott and Crossman 1973). The young often occur in slow-moving streams which are usually free of heavy vegetation. This species is uncommon in the vicinity of the J. H. Campbell Plant, including Pigeon Lake. Only two golden redhorses have been caught in Pigeon Lake by our sampling efforts (1977-1979); one was a 564-mm adult gillnetted at station M (influenced by Lake Michigan) in October 1977 and the other was a 603-mm female with moderately developed ovaries seined at station V (undisturbed Pigeon Lake) in June 1978. Pigeon Lake is heavily vegetated and thus does not offer the preferred habitat for this species. Golden redhorses spawn in spring later than other redhorses.

Quillback

Localized populations of quillback in the western drainage basin of Lake Michigan have been reported in the Grand and Macatawa rivers in Michigan (Becker 1976). Field collections in Pigeon Lake indicate that this species is not a common inhabitant of the lake, as only two were caught between 1977 and 1979.

Sea Lamprey

The only three adult sea lampreys (302-505 mm in length) observed were removed from impingement samples. The 505-mm specimen was determined to be a female with slightly developed ovaries. The sea lamprey is parasitic on other fishes. Adults in Lake Michigan migrate into tributary streams to spawn. This species was reported in the Pigeon River previous to the start of our study (Becker 1976). In October 1964 the Pigeon River and its tributaries were treated to control sea lampreys. Since most gear is ineffective for sampling sea lampreys, the status of this species in Pigeon Lake and the Pigeon River is unknown.

Chestnut Lamprey

One adult chestnut lamprey (157 mm) was collected in impingement samples in April 1978. Chestnut lampreys are parasitic on other fishes and are

generally found in larger rivers. In spring adults ascend small streams to spawn. Abundance of this species in Pigeon Lake and the Pigeon River appears to be low.

Lake Herring

Only one lake herring was caught during sampling; it was a female (389 mm, 425 g) caught at station M (Lake Michigan influenced Pigeon Lake) in a bottom gill net in June 1977. Age-length data for the Great Lakes area (Carlander 1969) indicate that this individual was at least 8-yr old. This species is apparently rare in the inshore waters of southeastern Lake Michigan.

Freshwater Drum

No freshwater drums were caught by our sampling in Pigeon Lake, however, a drum was caught by hook and line near station X (undisturbed Pigeon Lake) in August 1978. Becker (1976) reported that in lower Michigan this species is occasionally found in the lowermost portions of tributaries to Lake Michigan. The population of freshwater drum in the area of the J. H. Campbell Plant (including Pigeon Lake) is probably small.

Northern Hog Sucker

One northern hog sucker was observed in a non-sampled lot of impinged fish discarded in April 1978. This species is rare in Pigeon Lake. The northern hog sucker is basically a species of warm shallow streams and is infrequently found in shallow lakes near the mouths of streams (Scott and Crossman 1973).

FISH SPAWNING SITES

Pigeon Lake affords a variety of situations conducive to the spawning of indigenous species. The massive beds of vegetation are sites for broadcast spawners such as northern pike, carp, golden shiner and grass pickerel, while also providing cover for nest-building species (Fig. 16). Centrarchids such as the largemouth bass and sunfishes apparently use the shallow areas (0.6 m or less) of Pigeon Lake. Although these areas are choked with vegetation most of the time, these species apparently clear an adequate area of vegetation and maintain nesting sites. Another nestbuilder, the bowfin, utilizes even shallower water (0.3 m or less) for spawning. Aquatic plants and detrital material are not cleaned away but used as part of the nest.

Submerged logs and other suitable objects at depths of 0.6 m or less are used by bluntnose minnows and johnny darters as spawning sites. Many nests of johnny darters were found on the north shore of Pigeon Lake. Another percid species, the yellow perch, lays its eggs in long gelatinous sheaths in protected areas at depths up to 1 m.

The extensive vegetation in Pigeon Lake provides an optimum nursery area for most species, affording both protection from predators and an abundant benthos and zooplankton food source. Whether the dense vegetation allows for too much protection, thus causing abnormally high survival and consequent stunting of adults, is not known.

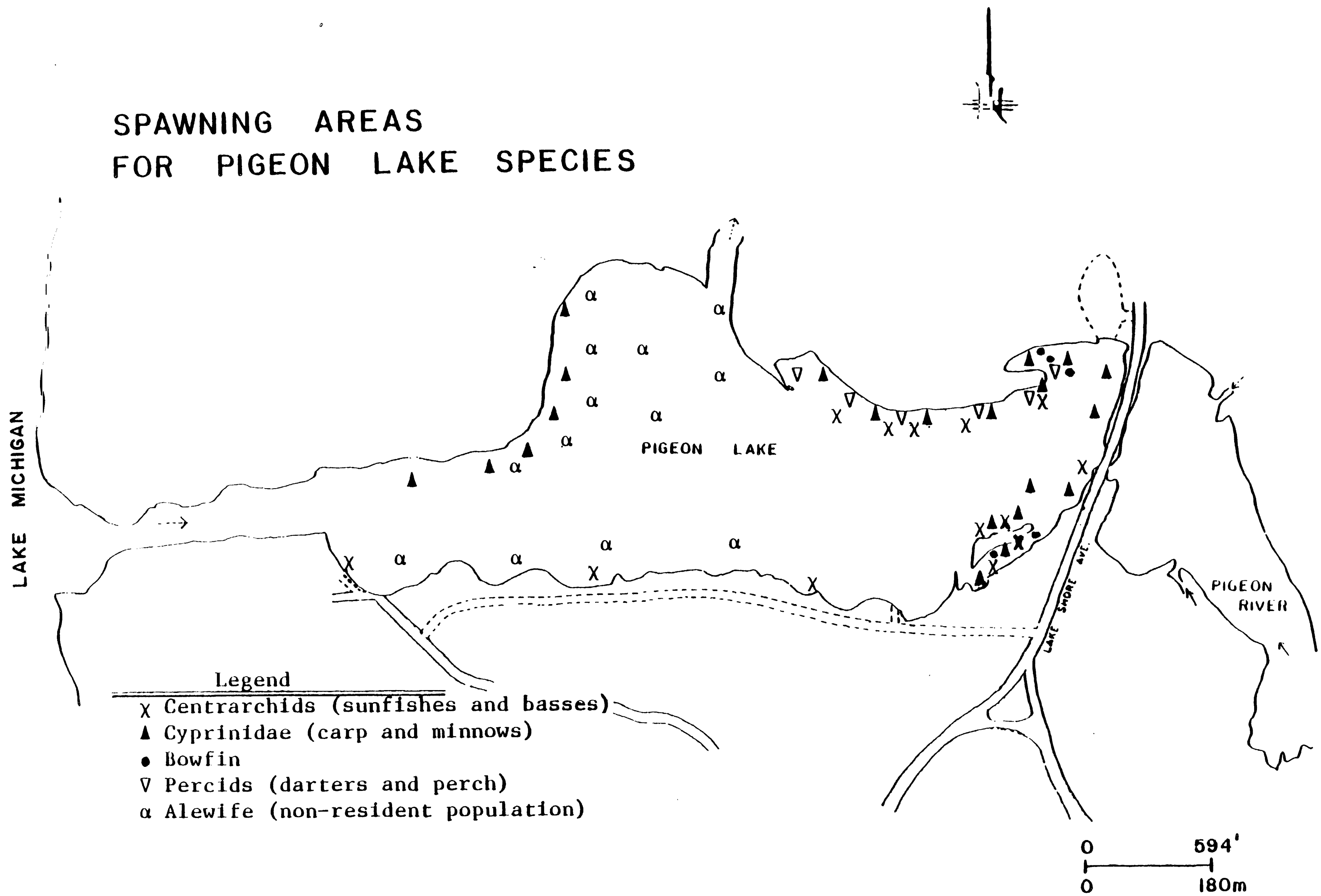

Fig. 16. Location of fish spawning areas in Pigeon Lake as determined by the presence of newly hatched larvae, eggs, and/or nests characteristic of the particular species.

SUMMARY AND CONCLUSIONS

Pigeon Lake, like many of Michigan's inland lakes, reached its present form and trophic state with considerable help from man. Because of many recreational and industrial uses, Pigeon Lake has perhaps been influenced by man to an even greater extent than other inland lakes in Michigan. Lake residents, some of whom have lived on the lake for 60 yr, characterize the lake as always having the same general form (minus the canals), with the access channel to Lake Michigan subject to considerable water level fluctuations. An historical account of the Port Sheldon area shows it to be a wild and tree-covered area in 1835 when a group of people tried to make it a great city. This area was a nesting site and on the migration route for passenger pigeons, from which the lake derived its name. Developers built many elaborate roads, a beautiful hotel, a lighthouse, and even a shipyard. However, they never concentrated on the key feature — giving Lake Michigan ships access to Pigeon Lake. Accounts relate that large ships could not cross into the lake because of the shallow and shifting sand bars. Large ships were unloaded by smaller boats which could apparently make it through. Eventually through money mismanagement, a recession, and lack of industry, the entire development collapsed.

The recreational and commercial attractions of Pigeon Lake are reflected in the many people who live and play in the vicinity and in the use of the resource by industry (J. H. Campbell Plant). The Pigeon Lake area is a juxtaposition of three different water bodies: Lake Michigan, the Pigeon River, and Pigeon Lake. As a result, there is a large diversity of plants, animals, and habitats. The esthetics of the landscape and water bodies, which are dominated by large sand dunes and Lake Michigan,are appreciated by a large number of people. It is thus no wonder that this area attracts the attention of hunters, fishermen, trappers, boat enthusiasts, and seekers of a pleasant abode, for either a permanent or second home. Planners who were searching for a source of condenser cooling water for the future J. H. Campbell Plant recognized the potential of the Pigeon Lake complex to provide a high quality, almost unlimited supply of water. The Pigeon River area also receives ash pond drainage from the J. H. Campbell Plant. The MDNR, knowing the recreational potential of Pigeon Lake and its connection to Lake Michigan, built a public access site on the lake. Lake Michigan boaters also use Pigeon Lake as a safe harbor.

There is some influence on the productivity of the lake by the inputs of fertilizer runoff from adjacent farmland. There is also a turkey farm which abuts the Pigeon River and which undoubtedly also contributes some nutrients to the Pigeon River. Nutrients from these sources enter Pigeon Lake, and along with local inputs from septic tanks and runoff, have caused the development of dense and extensive beds of aquatic plants. Algae blooms are common. The massive buildup and death of these plants each year contributes significant amounts of organic material to the sediments which also receive considerable inputs from runoff into the Pigeon River. Consequently, those parts of Pigeon Lake closest to the Pigeon River have a large accumulation of sediments.

Because of the nutrient load to Pigeon Lake from the Pigeon River watershed, it might be expected that the lake would be eutrophic. However, the limnology of the lake is strongly influenced by the flow of the Pigeon River, which affects the eastern basin, and the Campbell Plant's withdrawal of Lake Michigan water through Pigeon Lake for cooling purposes, which affects the

western basin. In effect, Pigeon Lake has two distinct sections. The eastern basin has the characterstics of a shallow, eutrophic lake with dense plant growth, chemical stratification at times, deep sediments, and an abundance of warmwater fish species. In the western section, which undoubtedly would resemble the eastern section without the influence of Lake Michigan water which flows through the lake, the dominant characters are deepness, more sandy substrates, little or no stratification, few beds of macrophytes, and a fish species complex including both warm- and cold-water species. Dredging the channel between Pigeon Lake and Lake Michigan to maintain water flow helps retard eutrophication of the western basin. Enforcing the finding that the western basin has been strongly influenced by the influx of Lake Michigan water is a comparison of its limnological and eutrophic state with that of the eastern basin and with comparable lakes in the immediate vicinity. Stony Lake and Lakes Macatowa, Muskegon, and Mona are all highly eutrophic, with high nutrients, algal blooms, dense plant beds, warmwater fish species complexes, stratification with severe dissolved oxygen depletions, and sediment buildup.

Aquatic plants are numerous and diverse in Pigeon Lake. In the eastern portion, where the Pigeon River enters Pigeon Lake, Scirpus, Sparganium, Typa, Pontederia, and Juncus were dominant emergents, while Myriophyllum, Ceratophyllum, Elodea, and Potamogeton were the major species comprising a very dense submergent flora. These same submergents, except Elodea, also dominated the shallows of the western basin. Scirpus was the principal emergent, which was most abundant along the eastern and northern shoreline. Over one-half of the lake is covered with submergent vegetation, which has been used extensively by Pigeon Lake fish and is clearly linked with the high productivity of fish in the lake.

Cyclopoid copepods were more abundant in Pigeon Lake than calanoids, but the most abundant group was Cladacera. Bosmina and Chydorus were the most numerous forms. The influence of Lake Michigan water on zooplankton distribution was distinct. Populations in the Lake Michigan-influenced section of Pigeon Lake were less diverse and were characteristic of Lake Michigan. Zooplankton in the undisturbed portion of the lake was more typical of southern Lake Michigan inland lakes.

Benthos present in Pigeon Lake was also diverse. Six distinct habitat types were identified and sampled in the lake during 1977, with 150 identifiable taxa observed. Chironomidae was the most diverse group, with 56 different forms identified. Trichoptera (caddisflies), Naididae and Tubificidae (oligochaetes), and Gastropoda (snails) were the other major groups which had 24, 36, and 7 identifiable forms respectively. Tubificidae was the group with the most numerous forms, comprising over 58% of the total animals collected. Chironomids (19%) and malacostracans (13%) were two other groups which comprised significant percentages of the totals collected.

The fish fauna of Pigeon Lake is diverse, with 71 species collected or observed during 1977-1979. The diverse habitats and proximity of Pigeon River and Lake Michigan are largely responsible for the many species documented in the lake. Of these, 49 are considered indigenous to the Pigeon Lake-Pigeon River system, while 16 are considered as originating from Lake Michigan. The Lake Michigan species include: lake whitefish, coho and chinook salmon, lake trout, brown trout, brook trout, and rainbow trout, rainbow smelt, burbot, alewife, ninespine stickleback, trout-perch, slimy sculpin, bloater (unidentified coregonids), longnose sucker, and lake herring. Of the 49

indigenous species, some (gizzard shad, shorthead redhorse, golden redhorse, quillback, channel catfish) may be strays from the Grand River. Others (hogsucker, blackside darter, creek chub) probably originated from the Pigeon River. Two forms, walleye and tiger muskellunge, are currently stocked by MDNR. A flathead catfish, sea lamprey, and chestnut lamprey were found on the plant's traveling screens. One freshwater drum was caught by hook and line.

Our data showed that of the 59 species collected via netting in Pigeon Lake during 1977-1979, six (alewife, spottail shiner, golden shiner, yellow perch, bluntnose minnow, largemouth bass) comprised over 95% by number of all those caught. Species dominance switched from alewife in 1977 (34%), to spottail shiner in 1978 (24%), to yellow perch in 1979 (43%). Of these six dominant species, four (alewife, golden shiner, spottail shiner, and bluntnose minnow) are forage fish. The remaining two, yellow perch and largemouth bass, are important sport fish in Pigeon Lake. Our survey of fishermen in 1979 revealed yellow perch to be the most often caught fish. Clearly, perch are abundant and the abundance of forage species in the lake should ensure good growth of resident piscivores such as bass, pike, and the occasional salmon and trout that frequent the lake.

The 16 species that we collected in Pigeon Lake that are considered mainly residents of Lake Michigan are evidence of the importance of this estuary to these fish. Of the 16, burbot, alewife, and ninespine stickleback have spawned in Pigeon Lake; others such as lake whitefish (larvae were collected in Pigeon Lake), slimy sculpin, and longnose and white suckers may spawn in the Pigeon Lake-Pigeon River system. Remaining species (the trout, salmon, lake herring) were frequenting Pigeon Lake-Pigeon River probably looking for suitable spawning sites and following cooler water into the lake. The construction of the jetties in Lake Michigan at the mouth of Pigeon Lake and the opening of the channel between the two lakes are largely responsible for the diversity of the Pigeon Lake icthyofauna. Of the three species most abundant in Lake Michigan catches, alewife, spottail shiner, and yellow perch, the latter two are indigenous to both Pigeon Lake and Lake Michigan. Spottails and alewife are seasonally abundant in Pigeon Lake and they use Pigeon Lake as a spawning and nursery area. A large resident population of yellow perch is present in Pigeon Lake and it is suspected that Lake Michigan yellow perch move into Pigeon Lake during warmer months. Yellow perch larvae, hatched in Lake Michigan, also enter Pigeon Lake with cooling water inflow during June. Rainbow smelt have been found in Pigeon Lake during their April spawning season along with some larval, YOY, and juvenile forms. However, Pigeon Lake and the Pigeon River are not important spawning, nursery, or forage areas for rainbow smelt. The common salmonids of Lake Michigan (coho and chinook salmon, rainbow, lake trout, brook trout, and brown trout) move into Pigeon Lake occasionally to spawn or forage. Rainbow trout have been planted in Pigeon Lake so it is not unusual that they are present in the lake during spring and fall. Coho and chinook also attempt to migrate up the Pigeon River to spawn. Although no chinook or coho are planted in Pigeon Lake, some natural reproduction may occur in the Pigeon River. The burbot is another species that may also spawn in Pigeon Lake or Pigeon River to some extent. Ninespine stickleback, trout-perch, and slimy sculpins are transient members of the Pigeon Lake fish fauna.

Sport fish common to Pigeon Lake include: largemouth and smallmouth bass, northern pike, yellow perch, crappies, and sunfishes. Largemouth bass are common in the east basin of Pigeon Lake. They spawn in late May-early June with YOY common inshore during summer. In 1978 there were 1132 bass 175-220 mm

in the lake. Largemouth bass greater than 220 mm varied from 471 in 1977 to 290 in 1978. We collected and released bass up to 419 mm. Aging of some of the fish showed bass up to 7 yr averaged 415 mm; by age 2 they were 214 mm.

Northern pike spawn in the shallow flooded areas of Pigeon River in early spring. In 1977-1978 we estimated that about 680 pike greater than 299 mm were present in the lake. Population estimates of pike between 175 and 299 mm increased from 630 in 1977 to 1260 in 1978. Good populations of northern pike exist in Pigeon Lake. Pike that we sampled averaged 313 mm at 1 yr and 739 mm at 8 yr. Pike fed on a large number of forage fish in Pigeon Lake.

Smallmouth bass were not common in Pigeon Lake, their center of abundance being in the Pigeon River-influenced area (east basin) of Pigeon Lake. They spawn in early spring. In our studies, we collected 5 in 1977, 14 in 1978 and 6 in 1979. They provide an additional game species for fishermen in the lake.

Yellow perch are abundant in Pigeon Lake, being the most numerous fish collected in 1979 and the most often caught sport fish according to our analyses. Perch spawn in the spring, usually over vegetation. Larvae were abundant through late May-early June. Perch grew to about 138 mm by November. Age-2 fish were 186 mm, while age-3 fish averaged 193 mm. Perch reproductive success fluctuated greatly among the years 1977-1979.

Pigeon Lake has changed considerably since 1835. Influences of man, both in the immediate water bodies and in the whole watershed, have molded the present physical, chemical, and biological structure of Pigeon Lake. Physical changes such as building of the road across the lake, Consumers Power Company's constructions, dredging and modifications, and the many cottages with their riprap and associated docks have altered the appearance of the lake. The lake has also been changed chemically. Nutrients and pesticides from a primarily agricultural watershed enter Pigeon Lake via Pigeon River and, along with nutrients generated from the local watershed, cause excessive growth of algae and aquatic plants. This process has been retarded in the western basin by the influx of Lake Michigan water. Biologically, the lake has also changed drastically. Lake Michigan species complexes have been altered, such that few endemic species remain today. Dominance has changed with the invasion of sea lampreys and alewives and the stocking of large numbers of salmonids. Thus, fish which may have used Pigeon Lake as a spawning ground are now present in very low numbers. Within Pigeon Lake itself, the major difference between benthic, zooplankton, and fish populations which existed during more pristine times and at present is the presence of Lake Michigan cooling water in Pigeon Lake. This water is usually colder than Pigeon Lake water and always contains high concentrations of dissolved oxygen. Thus, the inflow serves to prevent stratification of the water column, keeps basin waters well oxygenated, and provides a habitat which is more suitable for cold water benthos, zooplankton, and fish. In the more typical eastern basin which is uninfluenced by the cooling water, warmwater organisms are abundant.

Pigeon Lake today is an aquatic resource that definitely serves a large number of diverse groups including boaters gaining access to Lake Michigan, water skiers, fishermen, swimmers, Consumers Power Company (cooling water and ash pond discharge), trappers, cottage and permanent home owners, Lake Michigan sailors and boaters, and people who just enjoy the esthetics of the setting.

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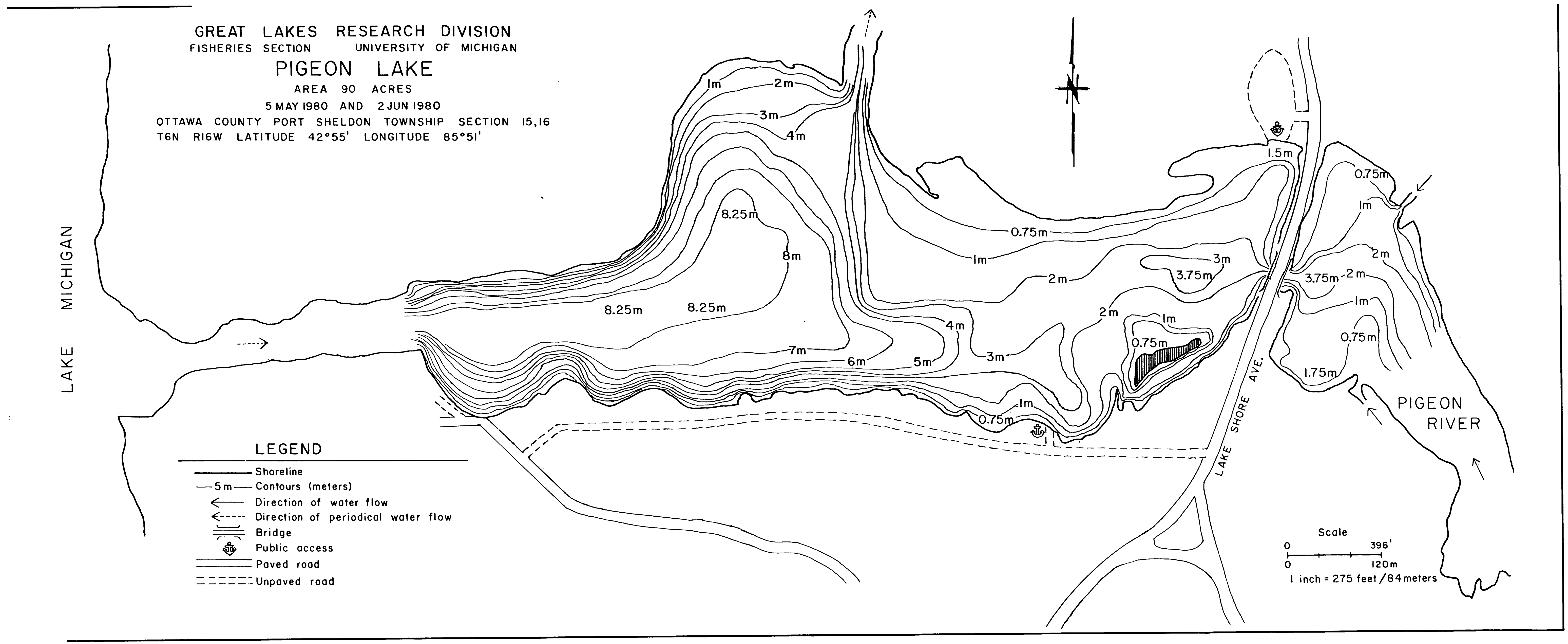
APPENDIX 1

Bathymetric Map of Pigeon Lake (T6N, R16W, S16),
Ottawa County, Michigan
Original Data Collected During Summer, 1980


GREAT LAKES RESEARCH DIVISION
FISHERIES SECTION UNIVERSITY OF MICHIGAN
PIGEON LAKE
AREA 90 ACRES
5 MAY 1980 AND 2 JUN 1980
OTTAWA COUNTY PORT SHELDON TOWNSHIP SECTION 15,16
T6N R16W LATITUDE 42°55' LONGITUDE 85°51'
LAKE MICHIGAN
PIGEON RIVER
LAKE SHORE AVE.
1m
2m
3m
4m
5m
6m
7m
8m
8.25m
0.75m
1.5m
1.75m
3.75m
LEGEND
Shoreline
5m Contours (meters)
Direction of water flow
Direction of periodical water flow
Bridge
Public access
Paved road
Unpaved road
Scale
0 396'
0 120m
1 inch = 275 feet/84meters